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FIRST PRINCIPLES OF CHEMISTRY.

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Ut potero, explicabo; nec tamen ut Pythius Apollo, certa ut sint et fixa, quæ dixero: sèd, ut homunculus, probabilia conjecturâ sequens.

Tusc. Quæst. Lib. I. c. 9.

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S. H. 1825

AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES

OF

CHEMISTRY

BY

EXPERIMENT.

By THOMAS THOMSON, M. D.,

REGIUS PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GLASGOW; F. R. S. LONDON AND EDINBURGH; FELLOW OF THE LINNÆAN SOCIETY; OF THE GEOLOGICAL SOCIETY; OF THE CAMBRIAN SOCIETY FOR THE ENCOURAGEMENT OF GEOLOGY, MINERALOGY, AND NATURAL HISTORY; OF THE IMPERIAL MEDICO-CHIRURGICAL AND PHARMACEUTICAL SOCIETIES OF ST. PETERSBURGH; OF THE ROYAL ACADEMY OF SCIENCES OF NAPLES; OF THE MINERALOGICAL SOCIETY OF DRESDEN; OF THE MINING SOCIETY OF FRANKFORT ON THE MAINE; OF THE CÆSARIAN NATURAL HISTORY SOCIETY OF MOSCOW; OF THE LITERARY AND PHILOSOPHICAL, AND NATURAL HISTORY SOCIETIES OF NEW YORK; &c.

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TO

Mr. JOHN DALTON, F.R.S., &c.,

M. GAY-LUSSAC, F.R.S., Mem. de l'Institut, &c.,

Sir HUMPHREY DAVY, Bart., P.R.S., &c.,

JACOB BERZELIUS, M.D., F.R.S., Kong. Vet. Acad. L., &c.,

WILLIAM HYDE WOLLASTON, M.D., V.P.R.S., &c.,

AND

WILLIAM PROUT, M.D., F.R.S., &c.,

TO WHOM

THE ATOMIC THEORY

IS INDEBTED FOR ITS ORIGINAL DEVELOPMENT

AND

FOR ALL THE IMPROVEMENTS WHICH IT HAS HITHERTO RECEIVED;

THIS ATTEMPT TO BRING THE SUBJECT

TO A STILL GREATER DEGREE OF SIMPLICITY AND PRECISION—

AS TO

THE BEST JUDGES OF ITS IMPORTANCE,

AND OF THE DIFFICULTIES TO BE SURMOUNTED,

AND MOST DISPOSED, IN CONSEQUENCE, TO VIEW

WITH INDULGENCE

ANY UNAVOIDABLE IMPERFECTIONS WHICH

THEY MAY PERCEIVE IN IT—

IS PRESENTED

BY THEIR SINCERE FRIEND AND HUMBLE SERVANT,

THE AUTHOR.

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TO

THE STUDENTS

OF

MEDICINE AND CHEMISTRY

IN THE

UNIVERSITY OF GLASGOW.

GENTLEMEN,

A CONSIDERABLE portion of the work which I now offer to the public, is already known to such of you as attended my course of lectures during the last three or four sessions. For I was in the habit of exhibiting to you a table of the atomic weights of the different bodies, as I succeeded in determining them, and of stating to you the experiments by means of which the results had been attained. I observed with pleasure the interest which the better informed and more intelligent students took in these investigations—while the numerous applications from various quarters for copies of my atomic tables, satisfied me that many of my students had understood the discussions, and had fully appreciated their importance.

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I have been induced to lay the result of my investigations before the public, chiefly for two reasons, with which I think it requisite to acquaint you. The first of these is, the great advantage which medical practitioners will derive from a knowledge of the atomic weights of bodies, and of the weights of the integrant particles of the salts, &c., which they have occasion to employ in their prescriptions. This knowledge will be easily acquired by a perusal of the following pages; and it will enable those who possess it to avoid some very awkward blunders, into which I have observed too many practitioners, even of considerable celebrity, frequently to fall, to the no little inconvenience of their patients. Indeed, till the atomic theory was pretty completely investigated, even chemists themselves were not exempt from such mistakes; and I could point out, if I thought proper, some remarkable examples of men who would take it amiss if the world did not give them credit for possessing much chemical science, falling into mistakes that no student of mine, who took the trouble to follow and understand the lectures delivered on chemistry in the College of Glasgow, would run any hazard of committing. It was a wish to enable my students to recollect with ease this important collection of indispensable information, and to put it in the power of other medical students, who are strangers to the lectures which I deliver, to avail themselves of the benefits to be derived from the facts and the tables in the following pages, that constituted one of

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the inducements which led me to lay the work before the world.

The second consideration which induced me to resolve upon publishing my atomical investigations, was one which more particularly concerns the medical students in the University of Glasgow. It was a wish on my part to shorten the discussions connected with the atomic theory, and with the composition of the salts, which I have hitherto thought it incumbent on me to introduce into my course of lectures. Henceforth, I shall have it in my power to refer you to the present publication for the proofs of the different fundamental points of importance. This will leave me much more time for illustration, and will enable me to make my future courses of lectures more entertaining and varied, without any diminution of the quantity of information which I have hitherto considered it as a point of duty to communicate. I shall be able too, hereafter, to enter more into detail respecting those parts of chemistry which are more intimately connected with the theory of medicine; for I need not observe to those gentlemen who have paid attention to the subject, that by far the most likely means of improving physiology, is a cautious application of chemistry to the investigation of the different constituents of the human body. An accurate knowledge of the chemical composition of every organ, and of the alterations produced on that organ by disease, would probably throw new and unex-

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pected light upon the nature and treatment of many diseases. Physiology hitherto has been handled almost exclusively by the anatomists. These gentlemen have acted with a zeal and industry that cannot be too much admired. They have examined the anatomical structure of every organ of the human body; ascertained the changes to which it is liable from disease; and compared it with the analogous organs in all the inferior animals. A great deal of important knowledge has been the result of this active examination: yet, after the anatomists have exhausted all their ingenuity, it must be admitted that our knowledge both of the organs and functions is still very imperfect. A new and more subtile species of anatomy remains still to be applied. Where the labours of the anatomist terminate, those of the chemist should begin. This chemical investigation of the animal body may be just said to be commencing at present: for it was not till the atomic theory was brought to considerable simplicity and perfection, that such an investigation was possible. It is easy to see that it must contribute prodigiously to the advancement of physiological knowledge. I have been long anxious to lay before my students the general results already attained by these chemical investigations. But the preliminary discussions into which I was obliged to enter, left us too little time at the end of the session, to enter upon them; and after having been at no little pains in collecting and arranging the different facts from sources not easily accessible to students in

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general, I have hitherto had the mortification to be obliged to pass them over, or at least to treat them in so general a way that my views could scarcely be understood. By referring my students hereafter to the facts contained in the following sheets, I shall have it in my power to shorten considerably the elementary part of my course, and be enabled to introduce at least a certain number of physiological lectures; by pointing out the general facts already ascertained, and the physiological consequences legitimately deducible from these facts. This is a branch of medical knowledge which has been much more attended to on the continent than in Great Britain. But from the intelligence and the zeal which the medical students in this country in general possess, I am satisfied that if the subject were once fairly started, it would become a favourite object of pursuit, and that it would advance to perfection with a degree of rapidity of which we can at present form but an imperfect idea.

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PREFACE.

The subject treated of in the following pages is of more importance than any other which can at the present moment occupy the attention of the chemist; since it is no other than an attempt to establish the fundamental principles of the science upon a sure and steady foundation. The analytical labours of the chemist and mineralogist depend upon these principles, and can only be accurate after their truth has been fully established. All the operations of the chemical manufacturer are equally dependant on them, and can only be prosecuted with perfect certainty and success by those who are acquainted with them. Several chemical manufacturers in this country have already availed themselves of the atomic theory to rectify their processes. This they have done to such an extent, that unless all the other manufacturers follow their example, they will find it impossible to compete with their more skilful rivals. One of the great objects of the present work is to reduce the whole doctrine of atoms to the utmost degree of simplicity and accuracy; so as to put it in the power of chemical manufacturers in general,

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to avail themselves of it in order to bring their processes to the requisite degree of precision.

Nor will the atomic theory prove less important to apothecaries and druggists, and preparers of medicines. It will point out the exact proportions of every substance to be used, and will enable them to attain their object in the most simple and direct manner, without any unprofitable waste by employing more or less of the different substances than is just requisite for the intended object. To them, and indeed to all medical men and medical students, the knowledge of the atomic theory is of the utmost consequence, and they will find the present publication of no little service to them. The tables contained in this work ought to occupy a place in every laboratory, and to lie upon the shop of every druggist, that he may have it in his power to have recourse to them to regulate all his processes.

The work which I now present to the public contains the result of many thousand experiments, conducted with as much care and precision as it was in my power to employ. They have occupied the whole of my time (except what was necessarily devoted to the duties of my situation,) for the last five years. All those experiments which I considered as fundamental, were repeated so often, and varied in so many ways, that I repose the most perfect confidence in their accuracy. I may therefore,

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perhaps, venture to express a hope, that the reader will not immediately judge them to be inaccurate, because they do not exactly coincide with the analytical results of other chemists. The processes of chemists have been so much rectified and improved of late years, and so much care is now generally bestowed upon experiments, that we may rely upon the result (provided the data employed be accurate) certainly within less than one per cent. I believe indeed, that the error in many of Berzelius' analyses does not exceed one thousandth part. But it is much more difficult to obtain substances in a state of complete purity than chemists in general are aware: it was in reducing the different salts which I employed, to the greatest possible degree of purity, that the greatest part of my time was wasted. I have in all cases in which it was in my power, deduced the atomic weights of bodies from the rigid analysis of the neutral salts into which they enter; because it is much easier to obtain neutral salts pure, than any of the metallic bodies which constitute their bases. Indeed, not a few of the metals have never yet been exhibited in a state of absolute purity. Berzelius has in general deduced the atomic weights of metals from experiments on these bodies themselves. This I believe to be the principal reason why his atomic weights so frequently differ a little from mine. For example, the atom of zinc deduced from his experiments is 4·03225; while the atomic weight obtained by me from the analysis of sulphate of zinc is 4·25. The reason of this difference I

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believe to be that the sulphate of zinc which I used was a pure salt, while zinc in the metallic state is never quite free from iron and some other impurities, all of which have a tendency to diminish its apparent atomic weight.

As the analysis of sulphate of zinc constitutes in some measure the foundation of the whole superstructure which I have endeavoured to rear, I made the analysis of it with the greatest possible care. My first analysis of it was inserted in the Annals of Philosophy, (second series) I. 247. But by some inadvertency, the quantity of water is stated at six atoms instead of seven, which is the true quantity. I cannot very well account for this mistake; for on looking back to my original analysis, I find it merely stated that 17 grains of sulphate of zinc were just decomposed by 13·25 grains of chloride of barium. Nothing is said about the state of the salt, which would enable us to account for the absence of an atom of water. But I have repeated the analysis of sulphate of zinc many times since the publication of that paper, and have made several of my practical students repeat it, and the uniform result has been seven atoms of water, and not six, as I there stated. If solutions of 17 grains of sulphate of zinc and 13·25 of chloride of barium be mixed, we shall find that the supernatant liquid, after the deposition of the sulphate of barytes, will become milky when mixed with sulphate of soda, showing that it still retains barytes,

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and consequently, that 17 grains of sulphate of zinc do not contain so much as 5 grains of sulphuric acid.

I have been in the habit, ever since the atomic numbers given in the present work were determined, to calculate the experiments of other chemists by substituting for the data which they employed, the more correct data which I myself possessed, and I have frequently found that the experiments, when so calculated, came much nearer the truth than the experimenters themselves were aware of. This was remarkably the case with respect to Mr. Faraday's experiments to determine the constituents of the chlorides of carbon, for a knowledge of which we are indebted to that very ingenious and accurate chemist. The imperfect data which he employed has given his experiments the appearance of greater inaccuracy than the truth: for when the specific gravities and atomic numbers given in the following pages are substituted for those which he used, his experiments almost coincide with the theoretic quantities.

In this country, the atomic weights which I here present to the public, have been already very generally adopted, so far as they are known. But on the continent, the numbers and tables of Berzelius are in common use. Berzelius' numbers are in general very near approximations to the truth; though I am persuaded that in very few instances he has actually reached it. His tables

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therefore, may be used without the risk of any great error, except those of the arseniates and phosphates, where the error is considerable; but they consist of much more complex numbers than mine, and the atomic weights are all kept out of view by his method of giving the constituents in 100 parts of the compound bodies. On the score of facility and simplicity, I consider my numbers as much preferable: indeed, the theory of Berzelius is so complicated and intricate, that it would be surprising if it were a true representation of what takes place in nature.

A few of my determinations of the atomic weights of various bodies, were published in the Annals of Philosophy, during the years 1820 and 1821. But on perceiving that I had occasionally fallen into mistakes by stating results deduced from particular views of a subject, before I had been able to consider it in all its bearings, I thought it safer to refrain, till I had brought the investigation to a conclusion, and then to lay the whole at once before the public. This was the reason that induced me to discontinue my original plan of publishing my labours in periodical essays, in proportion as the atomic numbers were determined.

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I HAVE been led by my desire of avoiding circumlocution, to make use of some terms in the following work, which may require explanation.

1. When the simple name of a compound occurs, it is to be understood that it is a compound of one atom of each constituent. Thus, oxide of zinc is a compound of one atom zinc and one atom oxygen. Sulphuret of bismuth, a compound of one atom bismuth and one atom sulphur. Sulphate of potash, a compound of one atom sulphuric acid and one atom potash.

2. When the acid which a salt contains is doubled, the doubling is denoted by prefixing the Latin word *bis* to the name. Thus, bisulphate of potash means a compound of two atoms sulphuric acid and one atom of potash. Biborate of soda is a compound of two atoms boracic acid and one atom soda.

3. When the base is doubled, this is denoted by prefixing the Greek syllable *dis*. Thus, disulphate of alumina is a compound of one atom sulphuric acid and two atoms alumina.

4. Three, four, &c. atoms of the acid are denoted by prefixing the Latin numerals, *ter*, *quater*,* &c. Three, four, &c. atoms of the base, by prefixing the Greek numerals, *tris*, *tetrakis*, &c.

5. When a metal is combined with oxygen in the proportion of two atoms metal to one atom oxygen, the compound is called a *suboxide*. Thus, suboxide of manganese is a compound of two atoms manganese and one atom oxygen, or, of one atom manganese and a half atom oxygen.

All the other terms employed will be understood without any farther explanation.

* The affix *quadro* having been already applied for this purpose by Dr. Wollaston, and having come into general use, I have thought it better to continue it than to use *quater*.

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AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES OF CHEMISTRY

BY EXPERIMENT.

CHAP. I.

HISTORICAL INTRODUCTION.

Chemists appear at all times to have admitted that the constituents of compound bodies are constant, whether we consider the elements themselves, or their proportions. But it was not till Chemistry had made considerable progress, that any thing like an analysis of the salts could be attempted. Homberg, so far as I know, was the first person who thought of determining the composition of these bodies. He contrived a hydrometer for ascertaining the specific gravity of acids. This instrument was similar to the weighing bottle at present in common use for the same purpose. It enabled him to judge, from the specific gravity, how much stronger one acid

was than another. But to estimate the quantity of real acid contained in each of those liquids, another process was necessary. And he proceeded in this way: He took an ounce of salt of tartar (carbonate of potash of the shops) and saturated it with each of his acid liquids, determining the weights of each necessary to produce the required effect. The liquid was then evaporated to dryness, and the dry salt left was weighed. The augmentation of weight which the ounce of salt of tartar had sustained, marked, in his opinion, the weight of acid which had combined with it. For example: 1 ounce of salt of tartar when saturated with nitric acid becomes 1·45 ounces. Hence he concluded that saltpetre is a compound of

Potash	100 *
Nitric acid	45
	145

In the same way he estimated the composition of muriate of potash, sulphate of potash, acetate of potash. It is unnecessary to give the results which he obtained, because Homberg, not having been aware that salt of tartar contained carbonic acid, increased the amount of the potash, and diminished that of the nitric acid by the whole quantity of carbonic acid previously united with the

* Mem. Paris, 1699, p. 48.

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potash. Of course, his results convey no idea whatever of the true composition of the salts which he attempted to analyze. We might, indeed, by subtracting the carbonic acid from the potash, and adding it to the acid, deduce the composition of these salts according to his experiments. These deductions being made, it will be found that saltpetre according to his experiments, is composed of

Potash	6
Nitric acid	6·68
	12·68

Numbers which, though not correct, constitute a pretty good approximation, and come much nearer the truth than the analysis of Kirwan, or even the more careful analyses of Berard or Wenzel.

The experiments of Plummer were made in the same way, and were subject to the same error.

In Dr. Black's celebrated Essay on Magnesia and Quicklime, he first pointed out the mistake of Homberg, and from some of his experiments deductions might be made respecting the constituents of some of the magnesian salts; but not being professed analyses, they have not attracted much of the attention of succeeding chemists.

Soon after the middle of the eighteenth century, attempts were made by different chemists

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to analyze various chemical substances, especially by Bergman, who had acquired so great a reputation, that his opinions carried with them a high degree of authority, and his analyses were for some time considered as models of accuracy —a character to which they are by no means entitled.

Wenzel discovers the relative weight of acids and bases.

I. For the first accurate set of experiments on the composition of salts, we are indebted to Wenzel, a German chemist, who published in 1777, a small work entitled, *Lehre von der Verwandschaft der Körper*, or *Theory of the Affinities of Bodies*. He had been struck with a phenomenon which had already drawn some attention from chemists; namely, that two neutral salts preserve their neutrality after mutually decomposing each other. Wenzel proved by a long series of very accurate analyses, that all the alkalies and earths bear the same ratio to all the acids. For example: if a given quantity of sulphuric acid be saturated by

9·75 barytes,
6·5 strontian,
6 potash,
4 soda,
3·5 lime,
2·5 magnesia,

the respective quantities of these earths and alkalies, which saturate a given quantity of each of the other acids, will be to each other as the

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numbers 9·75, 6·5, 6, 4, 3·5, and 2·5. When nitrate of lime, and sulphate of potash decompose each other, the nitrate of potash, and sulphate of lime formed, are neutral, because the relative quantities of potash and lime, which saturate a given weight of nitric and sulphuric acid, are the same. If we represent nitric acid by 6·75, then 6 of potash and 3·5 of lime will just saturate that quantity of it; and 6 potash and 3·5 lime will just saturate 5 of sulphuric acid. Nitrate of lime (abstracting the water) is composed of

Nitric acid	6·75
Lime	3·5
	10·25

and sulphate of potash of

Sulphuric acid	5
Potash	6
	11

When 10·25 nitrate of lime and 11 sulphate of potash are mixed, a double decomposition takes place, and there are formed

Nitrate of potash	Nitric acid	6·75
	Potash	6
		12·75

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Sulphate of lime	Sulphuric acid	5
	Lime	3·5
		8·5

And these new salts are neutral, because 6·75 nitric acid are neutralized both by 6 potash and 3·5 lime, and 5 sulphuric by 6 potash and 3·5 lime,*

It would appear a very extraordinary circumstance, if we were ignorant of the almost despotic power of fashion and authority over the minds even of men of science, that this luminous explanation of Wenzel, confirmed by the most accurate experiments which chemistry possessed, I do not say merely at the time when they appeared, but for many years after—experiments, which will even bear a comparison with those of Berzelius, made on purpose to demonstrate the truth of the very same principle which Wenzel first suggested—it would appear very extraordinary indeed, that neither the principle of Wenzel, nor the experiments by which it was confirmed, are noticed by any of the contemporary chemists, or seem to have attracted the smallest attention. Bergman was at that time in the height of his reputation. He published analyses of several of the salts, greatly inferior in point of accuracy to those of Wenzel. He, of course,

* I have not employed Wenzel's numbers to illustrate his opinions; but the more accurate numbers determined in the succeeding chapters of this work.

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did not perceive the existence of the principle which Wenzel had investigated. Yet the analyses of Bergman and of other chemists, though less accurate, and inconsistent with the fact which had led Wenzel to his investigation, were adopted by chemists in general, and thus their attention was withdrawn from one of the most important steps which the science has ever made, and the great improvement itself was delayed for more than thirty years.

The same opinions supported by Richter.

II. In the year 1792, Richter, who during the latter part of his life had the superintendence of the porcelain manufactory at Berlin, published a work entitled, *Anfangsgründe der Stochyometrie, oder Messkunst Chymischer Elemente, Elements of Stochyometry, or the Mathematics of the Chemical Elements.* This work consists of four thin volumes, which were printed at Breslau, during the years 1792, 3, and 4. It was followed by a periodical work, entitled, *Ueber die Neuern Gegenstände der Chymie, on the New Objects of Chemistry.* This work was begun in 1792,* and continued in twelve different numbers, or volumes, till the year 1807, the period of Richter's death. For he died on the 4th of May of that year.† In these works, he

* In my copy, the date of the first part is 1799, but it is a second edition. The second part was printed at Breslau in 1793. Hence I infer, that the first part appeared in 1792.

† Gehlen's Jour. (second series) IV. 127.

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endeavoured to give Chemistry a mathematical form. He examined the phenomenon observed by Wenzel, and explained it in the same way. He endeavoured to determine the relative capacity of saturation of the acids and bases, and attached a number to each, indicating this capacity. The following table exhibits these numbers.

Alumina	525	Fluoric acid	427
Magnesia	615	Carbonic	577
Ammonia	672	Sebacic	706
Lime	793	Muriatic	712
Soda	859	Oxalic	755
Strontian	1329	Phosphoric	979
Potash	1605	Formic	988
Barytes	2222	Sulphuric	1000
		Succinic	1209
		Nitric	1405
		Acetic	1480
		Citric	1683
		Tartaric	1694

Richter's labours in this important field produced as little attention as those of Wenzel. Berzelius ascribes this to two causes. 1. The great inaccuracy of Richter's experiments, which indeed cannot for a moment be put in competition with those of Wenzel. 2. The violent discussion between the antiphlogistic and phlogistic system, which had originated about the year 1787, and had not completely subsided at the time of Richter's death. The last of these

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reasons had, in all probability, the greatest influence.

But in Great Britain, where the importance of Richter's opinions were likely to have been early appreciated, another cause operated to prevent them from gaining much ground. The French revolution was at its acmé, when Richter began his Stochyometrical investigations, and all Europe was plunged into the bloodiest and most inveterate war, that has almost ever afflicted this part of the world. Great Britain soon became involved in the dispute, and gradually, not only bore the brunt of the war, but was, by degrees, deserted by all her allies, and at last left alone to wage war against all the world. Hence the intercourse between the men of science in Great Britain and on the continent was gradually interrupted. This, together with the little attention paid to German literature in this country, prevented us from being aware of the labours of Richter. My first knowledge of them was derived from a note in Berthollet's *Statique Chimique*, published in 1803, and I found it impossible to procure a copy till after the battle of Waterloo.

III. The notice in Berthollet's *Statique Chimique*, would probably have speedily drawn the attention of our countrymen to this most important department of chemistry, had not the genius of Dalton led him to a much more general view

Dalton's first views respecting the atomic theory.

of the subject, which has been usually called the atomic theory. I do not know when the ideas first occurred to him. In all probability they struck him by degrees, and were adopted in consequence of his own experimental investigations. I first visited him at Manchester, on the 26th of August, 1804, and on that day, he explained to me his notions respecting the composition of bodies. The ultimate particles of all simple bodies are, in his opinion, *atoms* incapable of farther division. These atoms (at least viewed along with their atmospheres of heat) are all spheres, and are all of them possessed of particular weights, which may be denoted by numbers. And he represented the atoms of the simple bodies by symbols. The following may be taken as a specimen of his method:

CHARACTERS.		RELATIVE WEIGHTS.
⊙	Hydrogen	1
ⓓ	Azote	5
○	Oxygen	6·5
●	Carbon	5
	BINARY COMPOUNDS.	
○⊙	Water	7·5
ⓓ○	Nitrous gas	11·5
●⊙	Olefiant gas	6
ⓓ⊙	Ammonia	6
●○	Carbonic oxide	11·5
	TERNARY COMPOUNDS.	
○●○	Carbonic acid	18

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CHARACTERS.		RELATIVE WEIGHTS.
①○①	Nitrous oxide . . .	16·5
●⊙●	Ethers	
⊙●⊙	Carburetted hydrogen . .	7
○①○	Nitric acid	18

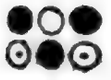
QUATERNARY COMPOUND.

	Oxy-nitric acid . . .	24·5

QUINQUINARY COMPOUND.

	Nitrous acid . . .	29·5

SEXTENARY COMPOUND.

	Alcohol	23·5

SEPTENARY COMPOUND.

	Nitrate of ammonia . .	31·5

Such was the view of the subject, which Mr. Dalton had taken before the month of August, 1804. Unless my recollection fails me, Mr. Dalton's theory was originally deduced from his experiments on olefiant gas and carburetted hydrogen. He found both composed of carbon and hydrogen; but the carbon in each being considered as the same, he found the hydrogen in the latter gas twice as much as in the former. This induced him to determine the ratios of these constituents in numbers, and to consider the olefiant gas as a compound of 1 atom carbon

and 1 atom hydrogen; and carburetted hydrogen of 1 atom carbon and 2 atoms hydrogen. The idea thus conceived was applied to carbonic oxide, water, ammonia, &c. and numbers representing the atomic weights of oxygen, azote, &c. deduced from the best analytical experiments which chemistry at that time possessed.

In the third edition of my System of Chemistry, published in 1807, I introduced a short sketch of Mr. Dalton's theory, so far as I understood it.* The same year a paper of mine on oxalic acid was published in the Philosophical Transactions, in which I showed that oxalic acid unites in two proportions with strontian, forming an oxalate and a binoxalate; and that supposing the strontian in both salts the same, the oxalic acid in the latter is exactly twice as much as in the former.† About the same time Dr. Wollaston showed, that bicarbonate of potash contains just twice the quantity of carbonic acid that carbonate of potash does; and that there are three oxalates of potash, viz. oxalate, binoxalate and quadroxalate, the acids in which are to each other as the numbers

* Vol. III. p. 424.

† Berard, in a paper on the oxalates, which he published by way of correction of mine, though his results are in general more erroneous than my own, denies the existence of binoxalate of strontian. I have often made the salt, and regularly exhibit it to my students. It differs very much from the oxalate.

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1, 2, 4. These facts gradually drew the attention of Chemists to Mr. Dalton's views, and induced several to adopt them, who were at first inclined to consider them as visionary. Among these I may mention Sir Humphrey Davy, who contributed so materially, a few years after, to confirm and extend this important theory.

In 1808 Mr. Dalton published the first volume of his New System of Chemical Philosophy. In the last chapter of that volume, consisting only of six pages, he gives us a concise view of his atomic theory; and in a plate at the end of the volume, he exhibits the symbols and atomic weights of 37 bodies, 20 of which were then considered as simple, and the other 17 as compound. In 1810, the second volume of this work appeared, in which he examined the combinations of oxygen with hydrogen, azote, carbon, sulphur, and phosphorus; and the combinations of hydrogen with carbon, sulphur and phosphorus; and showed that all these combined according to the laws of the atomic theory. He also examined the atomic weights and combinations of the alkalies and earths. The third volume of this most important work, though it has been printed for several years, the author, for reasons with which I am unacquainted, has thought proper to withhold from the public—and by so doing, has doubtless lost the right which he would have enjoyed, to

many curious discoveries, respecting the metalic combinations which he treated of in that volume.

He made the atom of hydrogen unity.

Mr. Dalton made choice of the atom of hydrogen for his unity. And in this he has been followed by Dr. Henry of Manchester, and by one or two chemical gentlemen in London. But this method has been rejected by almost all the British chemists, and by all the chemists, without exception, in Europe and America. The choice was unhappy, for very obvious reasons. 1. Because the atom of hydrogen is the most difficult of all to determine; and chemists are not yet all agreed about its weight. According to Professor Berzelius, it is only 0·0625; while the greater number of British chemists consider it as 0·125, or twice as much as Berzelius's estimate. Now, if we reckon the atomic weight of hydrogen by unity, and commit an error respecting its relation to that of other bodies; this error will affect the atomic weights of all other bodies, and will make them all either too heavy or too light; whereas, if we make choice of oxygen for our unity, any error respecting the atom of hydrogen will be confined to that atom, and will not affect the accuracy of the atomic weights of other bodies. 2. Hydrogen, so far as we know at present, combines with but few of the other simple bodies; while oxygen unites with them all, and often in vari-

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ous proportions. Consequently very little advantage is gained by representing the atom of hydrogen by unity; but a very great one, by representing the atom of oxygen by unity. For it reduces the greater number of arithmetical operations, respecting these bodies, to the addition of unity; and we see at once, by a glance of the eye, the number of atoms of oxygen which enter into combination with the various bodies. Thus, if the atom of manganese be represented by 3·5, and the weight of the various oxides of that metal be as follows:

1 Suboxide . .	4
2 Protoxide . .	4·5
3 Deutoxide , .	5
4 Tritoxide . .	5·5
5 Manganesous acid .	6·5
6 Manganesic acid .	7·5

It is obvious at once that the

Suboxide	contains	½ atom oxygen,
Protoxide	1	
Deutoxide	1 ½	
Tritoxide	2	
Manganesous acid	3	
Manganesic acid	4	

whereas, if we were to make the atom of hydrogen unity, these weights would be as follows:

Manganese . .	28
Suboxide . .	32

Protoxide . .	36
Deutoxide . .	40
Tritoxide . .	48
Manganesous acid .	56
Manganesic acid .	64

Numbers, which would not suggest the number of atoms of oxygen contained in each, with the same facility.

But the ratios should be as simple as possible.

3. All the knowledge that we are likely ever to acquire of the atomic weights of bodies, is merely the ratios of these weights. Now, it is obvious, that ratios are much more easily observed, and much more easily employed, the smaller the numbers are, by which they are denoted. Thus the ratio of 38741 to 116223 is the same as that of 1 to 3. But how very inconvenient would the great number of figures be, compared with the simple number 1 : 3. It is therefore highly important in chemistry, that the atomic weights of bodies should be represented by the smallest possible numbers. Now, when we make the atom of oxygen unity, the atomic weights of all bodies are represented by numbers eight times less than they would be if the atom of hydrogen be unity. It has been represented by some persons, in favour of the atom of hydrogen being unity, that in that case the atomic weight of every body is a whole number; whereas, when oxygen is the unity, fractions are frequently unavoidable. And these fractions, it is said, ren-

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der the atomic weights more complicated and unmanageable, than the greater size of the whole numbers deduced from hydrogen as a unity. But this view of the subject is quite erroneous. It will be shown in this work, that even when oxygen is made unity, nearly one half of all the atomic weights of bodies are whole numbers. And when fractions exist, they are always either 0·25, 0·5, or 0·75; except in four or five cases, when the fraction is 0·125, 0·375, or 0·625. If hydrogen be unity the atom of manganese is 28, while it is $3\frac{1}{2}$ if oxygen be unity. The atom of barytes on the former supposition is 78, on the latter $9\frac{3}{4}$. Now surely it will not be said that the fractional numbers are more unwieldy, or more unmanageable than the whole numbers; while in all cases of whole numbers the advantage on the side of the latter method is very great. Thus, if hydrogen be unity, the atom of uranium is 208, while if oxygen be unity it is only 26.

It was Dr. Wollaston that first suggested the representing of oxygen by unity. Berzelius, in his important investigations, adopted this method; and I did the same thing in the papers which I wrote on the Atomic Theory in the first series of the Annals of Philosophy. In the second series of the Annals, Mr. R. Philips has given a table of atoms according to the hydrogen scale.

Gay-Lussac's theory of volumes.

IV. For the next step in the progress of the atomic theory, we are indebted to Gay-Lussac. In the second volume of the Memoires D'Arcueil published in 1809, there appeared a paper by that acute chemist, *On the Combination of Gaseous Substances with each other.** In this paper he shows that the gases, considered in respect of their volumes, unite with each other in a very simple manner—one volume of one gas either combining with one volume, with two volnmes, or with half a volume of the other. Thus one volume of carbonic acid gas combines with one volume and with two volumes of ammoniacal gas; fluoboric acid gas combines with one volume and with two volumes of ammoniacal gas; protoxide of azote is a compound of one volume azotic, and half a volume oxygen gas; deutoxide of azote of one volume of azotic, and one volume of oxygen gas, &c. He proved also in the same paper, that when gases unite, the alteration of volume which they sustain, is always very simple. Deutoxide of azote is composed of one volume of azotic, and one volume of oxygen gas united without alteration of volume. Carbonic acid is composed of one volume carbonic oxide, and half a volume of oxygen gas condensed into one volume, &c.

This very important view of the way in which gaseous bodies unite, threw a new and unex-

* Pag. 207.

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pected light on chemical combinations. It has contributed very materially to simplify and perfect the mode of analyzing compound gases. It agreed admirably with the views of Mr. Dalton, as Gay-Lussac hints in his paper; and might have been employed by him in his investigations; and would have enabled him, had the specific gravity of gaseous bodies been more accurately known, at the time when he wrote, to have determined the atomic weights of the acidifiable combustibles with much more accuracy than he did. But Mr. Dalton's first volume was published, and probably the greater part of his second volume printed, before he had an opportunity of seeing Gay-Lussac's paper. And when he did see it, instead of welcoming it as an important addition to his own views, he set himself to show that Gay-Lussac's opinions were ill founded. But the subsequent researches of chemists have left no doubts about their accuracy; and if Mr. Dalton still withholds his assent, he is, I believe, the only living chemist who does so.

Investigations and discoveries of Berzelius.

V. When Professor Berzelius of Stockholm thought of writing his elementary treatise on Chemistry, the first volume of which was published at Stockholm in 1808, he prepared himself for the task by reading several chemical works, which do not commonly fall under the eye of the chemist. Among others, he read the

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writings of Richter, and was very much struck with the explanation there given, of the composition of salts, and the precipitation of metals by each other. It followed from the researches of Richter, that if we are possessed of good analyses of certain salts, we may, by means of them, calculate with accuracy the composition of all the others. Professor Berzelius formed immediately the project of analyzing a series of salts with the most minute attention to accuracy. While employed in putting this project in execution, Davy discovered the constituents of the alkalies and earths; and Mr. Dalton's theory came to his knowledge. All this enlarged his views as he proceeded, and induced him to embrace a much wider field than he had originally contemplated. His first analyses were unsatisfactory; but by repeating them, and varying the methods, he detected errors, improved his processes, and finally obtained results, which agreed exceedingly well with the theoretical calculations. These laborious investigations seem to have occupied him several years. The first knowledge which we obtained of them in this country, was in consequence of the publication of a letter addressed by Berzelius to M. Berthollet, in the 77th volume of the *Annales de Chimie*, about the beginning of the year 1811. In this letter he gives an account of his methods of analyses, together with the composition of 47

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compound bodies. He shows that when a metallic proto-sulphuret is converted into a sulphate, the sulphate is always neutral; that an atom of sulphur is twice as heavy as an atom of oxygen; and that when sulphite of barytes is converted into sulphate, the sulphate is neutral, there being no excess either of acid or base. From these, and many other important facts, he finally draws this conclusion: "In a compound formed by the union of two oxides, the one which (when decomposed by the galvanic battery) attaches itself to the positive pole (the acid, for example,) contains 2, 3, 4, 5, &c. times as much oxygen, as the one which attaches itself to the negative pole, (the alkali, earth, or metallic oxide)." Berzelius' Essay itself appeared in the third volume of the *Af handlingar i Fysik, Kemi och Mineralogie*, printed at Stockholm in 1810, where it occupies 114 pages. A translation of it was inserted almost immediately, in Gilbert's *Annalen der Physik*, and in the *Annales de Chimie*; but no English translation of this most important paper has ever been given to the public. In 1815, Berzelius applied his views to the mineral kingdom. His Essay was published in the fourth volume of the Af handlingar, and an English translation of it by Mr. Black was soon after printed. And some years after, Berzelius himself got a French translation of it published in Paris. The fifth

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volume of the Afhandlingar, published in 1818, is almost filled with papers on the same subject by Berzelius. His papers on the subject in that volume, amounting to nine—and all of them, especially the two last, are exceedingly important. The whole of these papers have appeared in the German Journals; and the greater number of them in the French and British Journals. In the 6th volume of the Afhandlingar, and in several of the latter volumes of the Memoires of the Stockholm Academy, this indefatigable experimenter has prosecuted the subject still farther. To him we are indebted for a much greater number of accurate analyses than to the whole chemical world put together. It is quite needless to observe how much the labours of Berzelius have contributed to the establishment of the atomic theory, and the immense progress which the science has in consequence made. In fact, we may almost say that it was by him that the theory was established. His analyses, in point of accuracy, infinitely surpass all those which had preceded him. He has embraced every department of chemistry with equal ardour, and every department lies under the deepest obligations to his indefatigable industry and profound sagacity.

Wollaston's scale of chemical equivalents.

VI. In the year 1814, there appeared in the Philosophical Transactions, a description of a synoptical scale of chemical equivalents by Dr.

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Wollaston. In this paper we have the equivalents or atomic weights of 73 different bodies, deduced chiefly from a sagacious comparison of the previous analytical experiments of others, and almost all of them exceedingly near the truth. These numbers were laid down upon a sliding rule by means of a table of logarithms, and over against them the names of the substances. By means of this rule, a great many important questions respecting the substances contained on the scale may be solved. Hence the scale is of great advantage to the practical chemist, and of course ought to be found in every laboratory. It will give, by bare inspection, the constituents of all the salts contained on it, the quantity of any other ingredient necessary to decompose, and the quantities of the new constituents that will be formed. The contrivance of this scale, therefore, may be considered as an important addition to the atomic theory. It rendered that theory every where familiar to all those who employed it. To it chiefly we owe, I believe, the currency of that theory in Great Britain; and the prevalence of the mode which Dr. Wollaston introduced, namely, of representing the atom of oxygen by unity, or at least by ten, which comes nearly to the same thing.

Prout's discovery of the relations between the atomic weights.

VII. In the year 1815, a paper appeared in the 6th volume of the Annals of Philosophy

by Dr. Prout, "On the Relation between the Specific Gravities of Bodies in their Gaseous State and the Weights of their Atoms." This paper displays a degree of sagacity that has seldom been exceeded in chemical investigations, and shows clearly that the author, if he chose, might rise to the highest eminence as a chemical philosopher. He proves, in the first place, that if air be a compound of 20 volumes of oxygen and 80 of azotic gas, then the specific gravities of these gases are

Oxygen	1·1111
Azotic	0·9722

He shows also, that the specific gravity of hydrogen gas is 0·0694: that if we reckon the atomic weight of hydrogen 0·125, that of oxygen is unity. The following table exhibits the numbers which he determined for several simple bodies—and most of his determinations were the result of direct and very accurate experiments:

1	Oxygen	1
2	Azote	1·75
3	Hydrogen	0·125
4	Chlorine	4·5
5	Iodine	15·5
6	Carbon	0·75
7	Sulphur	2
8	Phosphorus	1·75
9	Calcium	2·5
10	Sodium	3

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11	Iron	3·5
12	Zinc	4
13	Potassium	5
14	Barium	8·75

He observed that all these atomic weights are multiples of the atomic weight of hydrogen: indeed, that all of them are multiples of twice hydrogen, or 0·25, and most of them of 4 hydrogen, or 0·5. He observed also, that in general the specific gravity of the body in the gaseous state, may be obtained by multiplying its atomic weight by 0·5555, or half the specific gravity of oxygen gas; because the atom of oxygen is represented by half a volume, but that of most other substances by a whole volume.

Investigations of the author.

VIII. It was this admirable paper that satisfied me that new analytical investigations were still necessary to determine the atomic weights of bodies with perfect accuracy; and I formed the project of attempting the investigation myself by direct experiment. This project it was not in my power to commence till the summer of 1819, because it was not till the end of the preceding summer that the college of Glasgow, to which I had recently been attached, could furnish me with a laboratory. Since that period I have devoted the whole of my spare time to the investigation; and have resolutely withheld myself from entering upon several rather inviting fields, which have attracted general attention. My

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experiments have been very numerous, amounting to many thousands. At first my progress was very slow; because I was obliged to try many methods of investigation before I hit upon one sufficiently accurate for my purpose. But I found the subject become easier as I proceeded, and at last I acquired so much facility, that, during the last four months, I have been able to determine with tolerable accuracy the constituents of at least a hundred salts. My first object was to satisfy myself whether Dr. Prout's opinion, that the atomic weights of all bodies are multiples of that of hydrogen, was correct; because the establishment of its truth would at once give a simplicity to the atomic numbers, which had not been suspected, and would place the science of chemistry in a new and much more advantageous situation than it had ever occupied. The very numerous investigations, which will be exhibited in the following pages, will, I flatter myself, fully establish the truth of Dr. Prout's sagacious conjecture. For every substance, of which I could procure a sufficient quantity to enable me to examine it fully, has been found not only a multiple of the atomic weight of hydrogen; but, if we except a few compounds into which a single or odd atom of hydrogen enters, they are all multiples of 0·25 or of two atoms of hydrogen.

After determining the atomic weights of all

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the simple substances, and of many of their compounds, I next wished to examine the composition of a considerable number of salts, to see whether any law would develope itself respecting the quantity of water of crystallization which these bodies frequently contain. With this view a great number of salts were subjected to experiment; but the only obvious result is, that the number of atoms of water in salts, depends more upon the base than upon the acid: for the same base, in general, affects nearly the same number of atoms of water in its salts. But to this law there are many exceptions.

I now present the result of my investigations to the chemical public with considerable diffidence. For though I have been at the utmost pains to ensure accurate results; and often repeated what I considered as fundamental experiments eight or ten times, before I felt myself finally satisfied; yet the number of experiments gone through is so great, that it will be wonderful if, in some cases, I have not fallen into mistakes. I have made a point of relating my experiments (where I thought them fundamental) nearly as they were made: because, as I had no person to go over my calculations, which have been of necessity very numerous, though all of the simplest kind; it is very likely that I have not been always able to prevent the occurrence of some arithmetical errors in them.

And in all such cases the knowledge of the original experiments will put it in the power of the reader to calculate for himself, and to correct any errors into which I may have inadvertently fallen. The want of this attention in other writers has sometimes been severely felt by me, when an arithmetical error was conspicuous, without the requisite data for correcting it, or the means of knowing upon what number the error had fallen. Even the writings of Berzelius, though in general his numbers are very accurate, are not always free from this provoking uncertainty.

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CHAP. II.

OF THE ATOMIC THEORY.

Opinions respecting the ultimate elements of bodies.

Two opinions have divided philosophers respecting the nature of the ultimate elements of bodies, ever since they began to speculate on the subject. According to one party, these ultimate elements consist of *atoms*, or particles, incapable of farther division; according to another, *matter* is infinitely divisible, and consequently no such atoms can exist. These two opinions divided the ancients; and, after the revival of science in modern Europe, we find them equally dividing the philosophical world, and splitting it into sects. About the beginning of the last century, the infinite divisibility of matter was a favourite subject of discussion in Great Britain, and seems to have been universally adopted. Dr. Keil, in his Introduction to Natural Philosophy, devotes three lectures to this subject. In the first, he demonstrates the infinite divisibility of matter; in the second, he answers the objections which have been advanced against the truth of the doctrine; and in the third, he gives a number of examples of the extreme subtilty of matter, by showing how very minute a portion of certain substances may be made visible to the eye, or distinguished by the

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Leibnitz considered them as *atoms*.

sense of smelling. Leibnitz, on the other hand, adopted the opinion, that the ultimate elements of bodies are atoms; and, to obviate the mathematical objections of those who had embraced the doctrine of the infinite divisibility of matter, he considered these atoms as unextended. But numerous absurd consequences were still deducible from this opinion of Leibnitz, which were finally obviated by Boscovich; who considered the ultimate elements of bodies to be composed of unextended atoms; but demonstrated, in a most ingenious manner, from the law of continuity, that mutual contact between these atoms, or the bodies which they constitute, is impossible. According to the theory of Boscovich, the latest and most complete and ingenious which has been hitherto offered to the public, bodies are composed of unextended atoms, indivisible and homogeneous, possessing forces, which alternate from repulsive to attractive, according to the distance. This theory has been viewed in a favourable light by some of the most eminent philosophers who have appeared since the Theoria Naturalis of that mathematician was published. The opinion, that the ultimate principles of bodies are atoms which are incapable of farther division, seems, chiefly in consequence of the authority of Boscovich, to have become the prevailing opinion among the philosophers of the present time.

His view improved by Boscovich.

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With respect to the notion entertained by Boscovich, that the ultimate atoms of bodies are homogeneous, we are incapable at present of deciding whether it be well or ill founded. It is not likely that any of these ultimate elements has ever come under our inspection. All our simple bodies are most probably compounds. It *is* possible that the ultimate elements of bodies may be very few—it is even conceivable that they may be reduced to two; but in what way all the variety of bodies with which we are acquainted, could be produced from one single kind of elementary body or atom, I cannot, for my own part, form any conception.

If the atoms of bodies be incapable of farther division or diminution, it seems requisite that we should adopt the opinion of Leibnitz, that these atoms are unextended. This notion involves us in a maze of metaphysical subtilties, through which Boscovich has piloted his way with infinite address. But such discussions being quite unsuitable to a system of chemistry, or to the science of chemistry in its present state, it will be better to avoid them altogether. By *atom*, then, in the following pages, I would be understood to mean, the ultimate particles of which any body is composed, without considering whether the farther division of these particles be possible or not. They differ from each other in weight; but whether this difference be owing to

Meaning of the word *atom* in this work.

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a difference in their size or specific gravity, or of both together, I do not enquire.

The weights attached to the atoms of bodies, and deduced from the combinations into which they enter, merely express the ratios of the atomic weights, and have no reference whatever to the size or specific gravity of the atoms to which they are attached.

If a body be simple, it seems reasonable to believe, that its atoms or ultimate particles, are incapable of farther diminution or division: and consequently, that the supposition of the existence of half atoms involves an absurdity. Notwithstanding this, I have in certain cases, in the following pages, admitted the possibility of one atom of one body, uniting with one and a half, or with half an atom of another body. This admission has been viewed by many persons as improper and absurd, and as even involving an impossibility. I need hardly observe, that we can get rid of these half atoms with the greatest ease, by merely doubling the numbers representing the constituents of the compound. Thus, if an atom of iron weigh 3·5, and an atom of oxygen 1, and if we consider it as absurd to view *peroxide of iron* as a compound of 1 atom of iron, and $1\frac{1}{2}$ atom of oxygen; we have only to double 3·5, and 1·5, which are the two constituents of peroxide of iron. By so doing we get 7 = 2 atoms of iron, and 3 = 3 atoms of oxygen,

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and the peroxide of iron will be a compound of 2 atoms iron, and 3 atoms oxygen.

It is by no means unlikely, that this last method may represent the true composition of this oxide, and of the other compounds into which half an atom of oxygen, or of an acid or base, appears to enter. Nevertheless, I have been induced to represent the compound in the first way rather than the second; because it gives us smaller and simpler numbers, and enables us better to see the connection between the compound in question, and other compounds of the same constituents. If we represent the atomic weights of iron and its oxides as follows,

Iron . . .	3·5
Protoxide of iron .	4·5
Peroxide of iron .	5·0

we see at a glance that the protoxide is a compound of 1 atom iron + 1 atom oxygen; and that the oxygen in the peroxide is to that in the protoxide, as 3 to 2. But if we represent these atomic weights by

Iron . . .	3·5
Protoxide of iron .	4·5
Peroxide of iron .	10.0

by doubling the number of atoms in the peroxide, the relation between the oxygen, in the two oxides of iron, is much less evident. For the

sake of these advantages, which I consider as considerable, I have been induced to introduce half atoms in certain cases. But I would not be understood to support the abstract idea of the possibility of the existence of half atoms; but to have been actuated by the arithmetical facilities derived from the method which I have adopted. Those who prefer theoretical considerations to all such facilities, have only to double the atomic weight of all bodies containing half atoms, and they will get rid of the anomaly. The substances containing a half atom of oxygen do not amount to more than 7. A few occur containing half an atom of sulphur, and a few containing half an atom of acid.

Though the word *atom*, according to etymology, and indeed according to its usual acceptation, implies a particle incapable of farther diminution or division, I have been induced, for the sake of shortness, to apply it in the following pages with more latitude. When it is applied to the ultimate particles of *simple* bodies, it is taken in its usual and strict acceptation; but when it is applied to a compound body, it is to be understood as synonymous with *integrant particle*. Thus, an atom of iron, may be considered as implying an ultimate particle of that metal; but an atom of protoxide of iron means merely an integrant particle of protoxide of iron, which is a compound of 1 atom of iron and 1

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atom of oxygen; and consequently contains in reality two atoms. I have seldom applied the term atom to any of the salts; but if it were so applied, it would denote a substance containing a considerable number of atoms. Thus, an atom or integrant particle of sulphate of ammonia, is composed of

1 atom sulphuric acid	5
1 atom ammonia .	2·125
1 atom water .	1·125
	8·25

An integrant particle of sulphuric acid contains 4 atoms; an integrant particle of ammonia contains 4 atoms; and an integrant particle of water contains 2 atoms. So that an atom, or integrant particle of sulphate of ammonia contains no fewer than 10 atoms.

I doubt not, that this loose mode of applying the term atom will appear to many of my readers an improper liberty, and quite inconsistent with the precision necessary in chemical discussions. But my reason for doing so was, that I am of opinion, that we are not at present acquainted with any truly simple bodies. All our simple bodies are most probably compounds; and many of them may be afterwards decompounded and reduced to more simple principles by the future labours of chemists. If this opinion be true, I could not have employed the term

atom at all, or at least I could not have applied it to any of the bodies with which we are at present acquainted. This consideration appears to have induced several of the most distinguished chemists, both in this country and in France, to discard the term *atom* altogether. Thus, Dr. Wollaston, instead of *atom*, employs the phrase *chemical equivalent*, and Sir H. Davy employs the term *proportion*. But I did not see any reason for being so squeamish. The word *atom* is more convenient, shorter, and more distinct than any other word which I could think of. And when it is understood to signify merely *integrant particle* of the substance to which it is applied, it cannot, I think, have any tendency to mislead the reader.

2. Mr. Dalton, in the account of his atomic theory, which he gave to the public at the end of the first volume of his New System of Chemical Philosophy, employs some terms which have gradually got into general use, and which therefore require to be explained here. These terms are *binary*, *ternary*, *quaternary*, &c.

Binary, ternary, &c. explained.

1 atom of A + 1 atom of B = 1 atom of C, a binary compound.
1 atom of A + 2 atoms of B = 1 atom of D, a ternary
2 atoms of A + 1 atom of B = 1 atom of E, a ternary
1 atom of A + 3 atoms of B = 1 atom of F, a quaternary
3 atoms of A + 1 atom of B = 1 atom of G, a quaternary, &c.

Thus, protoxide of iron is a *binary* compound, composed of 1 atom of iron + 1 atom of oxygen.

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Carburetted hydrogen is a *ternary* compound, composed of 1 atom carbon and 2 atoms hydrogen: deutoxide of azote is a *ternary* compound, composed of 1 atom azote and 2 atoms oxygen. Ammonia is a *quaternary* compound, consisting of 1 atom azote and 3 atoms hydrogen; sulphuric acid is a *quaternary* compound, composed of 1 atom sulphur and 3 atoms oxygen. Nitrous acid is a *quinquenary* compound, composed of 1 atom azote and 4 atoms oxygen. Nitric acid is a *sextenary* compound, composed of 1 atom azote and 5 atoms oxygen. After these illustrations the terms *septenary*, *octonary*, &c. will be understood without any farther explanation.

Mr. Dalton's laws.

Mr. Dalton lays down the following rules, by which he thinks we should be guided in our opinions respecting chemical synthesis.

(1.) When only one combination of two bodies can be obtained, it must be presumed to be a *binary* one, unless some cause appear to the contrary.

(2.) When two combinations are observed, they must be presumed to be a *binary* and a *ternary*.

(3.) When three combinations are obtained, we may expect one to be a *binary* and the other two *ternary*.

(4.) When four combinations are observed,

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we should expect one to be *binary*, two *ternary*, and one *quaternary*, &c.

(5.) A binary compound should be always specifically heavier than the mete mixture of its two ingredients.

(6.) A *ternary* compound should be specifically heavier than the mixture of a binary, and a simple, which would, if combined, constitute it, &c.

5th and 6th not accurate.

With respect to these rules, the first four appear unexceptionable, unless the third should be objected to; but the fifth and the sixth do not appear to be warranted by a review of the compounds with which we are acquainted, compared with their constituents. It is in general true, that when two substances unite, they form a compound whose specific gravity is greater than the mean of that of the two constituents. But to this there are many exceptions. Deutoxide of azote has precisely the mean specific gravity of the two constituents. It has been demonstrated by Gay-Lussac, that it is composed of a volume of oxygen gas and a volume of azotic gas, united together without alteration of bulk. One volume protoxide of azote + $\frac{1}{2}$ volume of oxygen gas united, will form 2 volumes of deutoxide of azote; so that in the act of uniting, an expansion instead of a contraction takes place. The specific gravity of an alloy of 2 atoms tin

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and 1 atom lead ought to be 9·321; but it amounts only to 8·817, showing that an expansion has attended the union of these metals, instead of a contraction.

3. Berzelius, in his different papers upon the atomic theory, and especially in his Essay on the Theory of Chemical Proportions, has made us aquainted with the rules that guided him in the conclusions which he has drawn respecting the atomic weights of the different bodies, and the number of atoms of which the compound bodies are composed. The most important of these laws are the following: Berzelius' laws.

(1.) One atom of A may combine with 1, 2, 3, 4, &c. atoms of B. We do not know the limit; but it rarely passes 5 atoms.

(2.) Two atoms of A may combine with 3 atoms of B. But this is a much rarer case than the preceding.

(3.) When an acid and a base unite, the oxygen in the acid is a multiple of that in the base by 1, 2, 3, &c. The only exceptions to this law, exist in the combinations of phosphoric, arsenic, and nitric acids with bases.

(4.) Oxides containing only 1 atom of oxygen, united to 1 atom of base, have very weak affinities for acids.

(5.) Oxides with 2 atoms of oxygen have very strong affinities for acids.

(6.) Oxides with 3 atoms of oxygen have weak

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affinities for acids. Some of them possess rather the properties of acids than of bases.

(7.) Most acids contain 3 atoms of oxygen; but some contain 2, 4, 5, 6, 8 atoms.

The first two of these laws are unexceptionable; being merely a statement of what every person, who has attended to the combinations of atoms with each other, must have observed.

The third law not universally true.

The third law is not so obviously just, and will require some consideration before it can be adopted. The greater number of the alkaline bases, as will appear from the following pages, contain only 1 atom of oxygen: and the neutral salts being compounds of 1 atom acid, and 1 atom base, it is clear that in all of them, the oxygen of the acid will be a multiple of the oxygen of the base; because every number is a multiple of unity. Hence every acid, whether it contain 1, 2, 3, or more atoms of oxygen, must, in fact, contain a number of atoms of that principle, equal to the oxygen in the base, multiplied by the number of atoms of oxygen in the acid. This must necessarily be the case, because the oxygen in every acid always amounts to a whole number of atoms. Berzelius, indeed, considers almost all the salifiable bases as containing two atoms of oxygen. But he represents the neutral salts as compounds of 1 atom base, and two atoms acid. Now, whatever the number of atoms of oxy-

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gen may be which an acid contains, it is obvious that the double of it must constitute an even number, or a number divisible by 2, and consequently a multiple of 2.

As far then as the neutral salts are concerned, Berzelius's law expresses nothing more, than that the salifiable bases are mostly protoxides—a pretty remarkable fact, though Berzelius himself was not aware of it. Even in the neutral phosphates, arseniates, and nitrates, and in the biphosphates, binarseniates, and binitrates, the same law will hold. It is only in the subsalts, and in those salts that contain peroxides united to an acid, that we can see whether this supposed law of Berzelius be general or not. For example, sulphuric acid contains 3 atoms of oxygen : now, it would be a very remarkable circumstance indeed, if no protoxide exist, of which 2 atoms are capable of uniting with 1 atom of sulphuric acid. There are but few subsalts known at present; yet when I come to treat of the salts, I think I shall be able to show examples of subsalts, which are inconsistent with Berzelius's supposed law. Peroxide of iron is a compound of 1 atom of iron, and $1\frac{1}{2}$ atom of oxygen ; consequently, whether it combine with 1 atom, 2 atoms, or 3 atoms, of sulphuric acid, it is obvious that the oxygen of the acid must be a multiple of the oxygen of the base : For $3=1{\cdot}5 \times 2$. But phosphoric acid is a compound of 1 atom phosphorus, and 2 atoms

of oxygen. Hence, Berzelius's law could not hold with perphosphate of iron, unless it consisted only of 1 atom peroxide of iron united to 3 atoms of phosphoric acid. We are acquainted at present with but very few compounds of peroxides with acids; yet, when I come to treat of the salts, I think I shall be able to point out some which are not combined according to Berzelius's law. It would, therefore, be extremely hazardous to employ this law as a guide to enable us to determine the quantity of oxygen united to bases. This, Berzelius is frequently in the habit of doing, and I think it has misled him in a variety of cases. These I may perhaps notice more particularly hereafter.

4th, 5th, and 6th laws, founded on views peculiar to Berzelius.

Berzelius's fourth, fifth, and sixth laws, are founded entirely upon his own peculiar views respecting atomic combinations, and cannot, therefore, serve as guides to us. So far from being of opinion that the combinations of 1 atom base, and 1 atom oxygen, constitute weak alkaline bodies, I consider them as the strongest of all: for the fixed alkalies, alkaline earths, and most of the metallic oxides which constitute salifiable bases, belong to this class of bodies.

To the oxides which Berzelius considers as composed of 1 atom base, and 1 atom oxygen, I give the name of *suboxides*, and believe them to be compounds of 2 atoms base, and 1 atom oxygen. They have but a weak affinity for acids;

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though most of them combine, at least, with muriatic acid. Hitherto, only a few of these suboxides have been noticed by chemists, though it is likely that they will increase considerably hereafter.

It is unnecessary to make any observations upon Berzelius's seventh law; it expresses merely his opinion respecting the composition of acids. If the views which I have given in the following pages be entitled to any confidence, it will be seen that eleven of the acids contain three atoms of oxygen; namely, 7th law in the same predicament.

1 Oxalic	4 Arsenic	7 Succinic	10 Tungstic
2 Sulphuric	5 Molybdic	8 Benzoic	11 Fluoboric.
3 Chromic	6 Acetic	9 Formic	

Six contain only one atom of oxygen; namely,

1 Silica	3 Hyposulphurous	5 Columbic
2 Phosphorous	4 Oxide of tellurium	6 Fluoric.

Twelve contain two atoms; namely,

1 Carbonic	4 Sulphurous	7 Selenic	10 Uranitic
2 Boracic	5 Titanic	8 Antimonic	11 Uric
3 Phosphoric	6 Arsenious	9 Molybdous	12 Fluosilicic.

Two contain four atoms; namely,

Manganesic and citric.

Three contain five atoms; namely,

Hyposulphuric, tartaric, chloric.

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One contains seven atoms; namely,

Perchloric;

And one eight atoms; viz.

Saclactic.

Rules by which the investigations of the author were regulated.

4. I shall now briefly notice the considerations by which I have been regulated in the following investigations, and by which I have been led to fix upon the atomic numbers contained in this work.

(1.) The only useful information respecting the atoms of bodies, which we are likely to acquire, is that of the ratios which these weights bear to each other. Hence, the smaller the numbers employed to represent these atoms, the more useful will they be to the practical chemist.

(2.) Neutral salts (that is, salts which are neither acid nor alkaline) are probably composed of 1 atom of acid united to 1 atom of base. When the salt has acid qualities, it is probably a compound of 1 atom base, and more than 1 atom of acid. When it possesses alkaline qualities, it is probably a compound of 1 atom acid, and more than 1 atom of base: but to these rules there are many exceptions. Some acids have not the property of neutralizing the bases, in however great a proportion they are combined with them. This is the case with boracic acid;—even a compound of 8 atoms of boracic acid, and 1 atom of

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soda, possesses alkaline characters. We cannot, therefore, determine the proportion between the atoms of acid and base in the borates, by their neutrality. The same thing holds with the alkaline carbonates, which always possess alkaline properties whatever be the number of atoms of carbonic acid they contain. On the other hand, there are several bases, as the oxides of copper and zinc, which do not destroy the acid properties of acids in how great a proportion soever they be combined with them. Such salts alway redden vegetable blues, and possess certain characters denoting the presence of an acid.

(3.) The weights of certain acidifiable bases were determined by their relation to oxygen. Thus it was found that 2 of sulphur is capable of combining with 1, 2, and 3 of oxygen. Hence, it was concluded, that 2 represents the atomic weight of sulphur, and that the atomic weights of the compounds of sulphur and oxygen are,

						ATOMIC WEIGHT.	
1.	2 sulphur	+	1 oxygen	=	3		hyposulphurous acid.
2.	2	+	2	=	4		sulphurous acid.
3.	2	+	3	=	5		sulphuric acid.

In like manner, 0·75 carbon unites with 1 and 2 of oxygen. Hence 0·75 represents an atom of carbon, and the atomic weights of the compounds of carbon and oxygen are,

1.	0·75 carbon	+	1 oxygen	=	1·75	carbonic oxide.
2.		+	2	=	2·75	carbonic acid.

1·75 azote combines with 1, 2, 3, 4, 5 of oxygen. Hence

1.	1·75 azote	+	1 oxygen	=	2·75	protoxide of azote.
2.	1·75	+	2	=	3·75	deutoxide of azote.
3.	1·75	+	3	=	4·75	hyponitrous acid.
4.	1·75	+	4	=	5·75	nitrous acid.
5.	1·75	+	5	=	6·75	nitric acid.

(4.) After determining in this way, the atomic weights of some of the most common and important acids, I examined the neutral salts which these acids formed by uniting with the salifiable bases, and determined the proportion between the weights of the acid and base in each. From this I deduced the atomic weight of the base. Thus, knowing that the atomic weight of sulphuric acid is 5, and that sulphate of potash is a compound of

Sulphuric acid	5
Potash	6
	11

I drew as a conclusion, that the weight of an integrant particle of sulphate of potash is 11, and that an atom of potash weighs 6. By this method, I determined the atomic weights of most ofthe salifiable bas es.

(5.) I now combined some of the most common and important of these salifiable bases with the other acids—thus forming a new set of neutral salts. These were analyzed with great

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care, and the ratio between the acid and base in them determined. From this I deduced the atomic weights of the other acids. Thus, knowing that the atomic weight of soda is 4, and that neutral anhydrous acetate of soda is composed of

Acetic acid	6·25
Soda	4
	10·25

I drew as a conclusion, that 10·25 represents the weight of an integrant particle of anhydrous acetate of soda, and that 6·25 is the atomic weight of acetic acid.

In this way, the atomic weights of all the acids and bases were determined from neutral salts, and they represent the ratios in which the acids and bases saturate each other, expressed in the smallest numbers consistent with the notion, that the atomic weight of oxygen is unity.

The methods employed to determine the atomic weights of the simple bodies, of which these acids and bases are composed, will be understood by perusing the different chapters of the following work.

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CHAP. III.

OF THE SPECIFIC GRAVITIES OF OXYGEN AND HYDROGEN GASES.

It is only of late years, that the great importance of an accurate knowledge of the specific gravities of the gases has been fully appreciated. Three different sets of experiments on the subject have been laid before the public. The first was by Biot and Arago, which was published in the *Memoires de l'Institute*, for 1806, p. 320. They give a table of the specific gravity of a few of the most important gases, and describe the processes by which they were determined. The next was a paper inserted by me in the 16th volume of the Annals of Philosophy. It contained the specific gravities of 23 gases. The experiments were made with every precaution which I could think of, to secure me against mistakes; and I believe them to come as near the truth as we can reach, with our present means of operating. The third set was by Messrs. Berzelius and Dulong, and published in the *Annales de Chimie et de Physique*, for 1820.* They determined the specific gravity of oxygen, hydrogen, carbonic acid, and azotic

Experiments already made to determine these gravities.

* Vol. XVI. p. 386.

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gases with great care, and gave a table of the specific gravity of 21 bodies, calculated from these data, and the doctrines of Gay-Lussac, respecting the mode in which gases combine. These results of Berzelius and Dulong differed so much from mine as to excite my surprise; while the well known accuracy and dexterity of these gentlemen naturally induced me to distrust my former results, and to endeavour to verify them by new experiments. After a good many fatiguing trials made with every precaution that I could think of, I was unable to find any flaw in my former results, or to reconcile them with those of Berzelius and Dulong. I was satisfied that I could not approach any nearer the goal by the direct road. But another method of proceeding occurred to me, susceptible, I thought, of an unlimited approximation to the truth. This method applied only to oxygen and hydrogen gases. But these bodies constitute the keystone of the building. And were their specific gravities once determined with precision, we are enabled, by means of the atomic theory, to determine with accuracy the specific gravities of most of the other gases.

Method of the author.

I propose in this chapter to lay before the reader, a set of experiments which seem to me to settle the specific gravities of these two gases, without any error which can much exceed

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the ten thousandth part of the whole. The accuracy of the process, indeed, is only limited by the delicacy of the balance made use of in the experiments. And my balance enabled me to weigh to within less than one hundred thousand part of the weight.

It has been demonstrated by Gay-Lussac and Humboldt, that water is a compound of oxygen and hydrogen gases, in the proportion of one volume of the former, to two volumes of the latter. It occurred to me that by a very careful analysis of water, the relation between the volumes and the weights of these gases might perhaps be determined. These experiments were made by means of zinc, and before their accuracy can be appreciated, it will be necessary to know the exact composition of the oxide of zinc. I shall therefore divide this chapter into three sections. In the first section, we shall determine the composition of oxide of zinc; in the second, the specific gravity of oxygen gas; and in the third, the specific gravity of hydrogen gas.

SECT. I.

OF THE COMPOSITION OF OXIDE OF ZINC.

I SHALL be under the necessity to state in this section a variety of facts, which may seem at first sight foreign to the subject in view; but

which are requisite, in order to enable the reader to judge of the justice of the conclusions which are to be drawn. Some of the details may appear needlessly minute; but I must request the reader's attention to them, because they constitute the foundation of the whole fabric which I mean to build.

The zinc of commerce does not answer for the experiments which I am going to describe. It is never quite free from carbon, which has a material effect in increasing the specific gravity of the hydrogen gas, obtained by dissolving it in sulphuric acid. It contains, likewise, small quantities of several other metals, and does not dissolve completely in sulphuric acid. The zinc which I used, was obtained by exposing common zinc to a white heat in a stone-ware retort, luted to a receiver nearly filled with water. At this temperature, the zinc is sublimed, and freed from all its impurities, except a trace of cadmium too minute to occasion any sensible error in the result of the experiments. The zinc thus distilled over, should be melted in a crucible, and poured upon the surface of a clean, smooth sandstone. We thus obtain it in a thin sheet, which can be easily broken into small pieces to suit the object in view.

Composition of oxide of zinc.

21·25 grains of this zinc were introduced into a small green glass retort, the weight of which had been previously determined. As much

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very weak but pure nitric acid as was fully sufficient to dissolve the whole zinc was introduced into the retort. As soon as the metal was all dissolved, a receiver was applied to the retort which was placed in hot sand, and allowed to remain till the whole liquid contents had distilled over. The liquid in the receiver was saturated with carbonate of ammonia, and boiled for some time to see whether it contained any zinc; but no precipitate appeared.

The retort, thus freed from its liquid contents, was placed upon a charcoal fire, and kept for about an hour in a dull red heat. This completely decomposed the nitrate of zinc, which existed at first in the retort, dissipated the nitric acid, and left nothing behind but the 21·25 grains of zinc, now converted into an oxide. Being placed in the scales, the zinc, by being oxydized, was found to have increased in weight 5 grains. Thus, it appears that oxide of zinc is composed of

Zinc	21·25
Oxygen	5
	26.25

or, dividing each constituent by 5 to bring them to their lowest terms, of

Zinc	4·25
Oxygen	1
	5·25

As zinc combines with oxygen in only one proportion, it is reasonable to conclude that the oxide is a compound of 1 atom zinc and 1 atom oxygen. If this supposition be admitted, the atom of zinc is obviously $4\frac{1}{4}$ times heavier than the atom of oxygen. And if we represent the atomic weight of oxygen by unity, then the atomic weight of zinc will be 4·25 and the integrant particle of oxide of zinc will weigh 5·25; or in other words, 5·25 of oxide of zinc will just saturate an integrant particle of any acid with which it is capable of combining. The law holds with all acids; but I shall at present verify it only by referring to three acids; namely, the sulphuric, carbonic, and arsenic acids. It will be shown in the 5th, 1st, and 7th sections of the sixth chapter of this work, that the atomic weights of these acids are as follows:

Sulphuric acid .	5
Carbonic acid .	2·75
Arsenic acid .	7·75

Now, 5·25 of oxide of zinc will just saturate 5 of sulphuric acid, 2·75 of carbonic acid, and 7·75 of arsenic acid; or in other words, the sulphate, carbonate, and arseniate of zinc, supposing them anhydrous, are composed as follows:

1. SULPHATE OF ZINC.

Sulphuric acid .	5
Oxide of zinc .	5·25

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2. CARBONATE OF ZINC.

Carbonic acid .	2·75
Oxide of zinc .	5·25

3. ARSENIATE OF ZINC.

Arsenic acid .	7·75
Oxide of zinc .	5·25

We shall verify this statement by a rigid analysis of these three salts.

1. SULPHATE OF ZINC.

Analysis of sulphate of zinc.

Sulphate of zinc, or white vitriol, is a well known salt which crystallizes in beautifully transparent four-sided prisms, terminated by four-sided pyramids; or if the crystallization be rapid, it assumes the form of long slender white needles. However carefully prepared, it always reddens vegetable blues. But it crystallizes also with an excess of acid. In that case, the crystals assume the form of large flat rhomboids, which are not altered by exposure to the air, and may be raised to the temperature of at least 500° without being deprived of their excess of acid.*

* I am doubtful whether this salt constitutes a truly distinct species. I found its composition

$1\frac{1}{3}$ atom acid	6·66
1 atom oxide	5·25
8 atoms water	9·00
	20·91

or, it consists of one atom of the protohydrate of sulphuric acid, combined with three integrant particles of the neutral salt.

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18·125 grains of the neutral sulphate of zinc were dissolved in distilled water, and precipitated by a solution of carbonate of soda. The precipitate was separated from the liquid by means of a double filter, consisting of two pieces of unsized and well washed printing paper, made previously of the same weight. The carbonate of zinc on the filter was washed with distilled water, till the liquid which passed through ceased to render muriate of barytes muddy. The filter was suspended in a linen bag above the sand bath, in a temperature of 85°, till it was apparently dry; and it was finally left for some time in a temperature of about 212°. It was afterwards weighed by placing the two filters in opposite scales, and adding weights till the two scales were exactly counterpoised. The weight of the carbonate of zinc was exactly 8 grains. It was put into a platinum crucible, which was covered with a lid, and exposed for half an hour to a red heat. There now remained 5·25 grains of oxide of zinc.

Thus it appears, that 18·125 grains of sulphate of zinc, in crystals, contain 5·25 grains of oxide of zinc. It is still easier to prove that the sulphuric acid contained in this quantity of the salt weighs precisely 5 grains.

But it will be necessary to state, in the first place, that when 15·5 grains of crystallized

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muriate of barytes are exposed to a red heat, they lose 2·25 grains of their weight, and are converted into 13·25 grains of chloride of barium. When 13·25 grains of chloride of barium are dissolved in water, the solution contains just 9·75 grains of barytes. Now, 9·75 represents the atomic weight of barytes, which requires for saturation exactly 5 of sulphuric acid. And 14·75 parts of sulphate of barytes contain just 5 parts of sulphuric acid.

A little distilled water was put into two small cylindrical glass jars, and 18·125 grains of crystallized sulphate of zinc were dissolved in the one of these, and 13·25 grains of chloride of barium in the other. The two liquids being mixed, a double decomposition took place, and sulphate of barytes precipitated in the state of a white powder. This precipitate being collected, washed, dried, and heated to redness, weighed 14·75 grains, and therefore contained exactly 5 grains of sulphuric acid. A few drops of the colourless liquid from which this sulphate had precipitated, were put into a watch glass, and a small quantity of muriate of barytes mixed with it; but it did not become in the least muddy or even opal coloured, showing that it contained no sensible quantity of sulphuric acid. For I find that 1 grain of glauber salt (containing 0·2469 grain of sulphuric acid) dissolved in 12,000 grains of water, is sensibly

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precipitated by muriate of barytes. Hence it is clear, that in the present experiment, the quantity of sulphuric acid remaining in the liquid could not amount to $\frac{1}{10302}$ of a grain. Indeed, as the quantity of liquid never amounted to 1000 grains, the sulphuric acid remaining in solution, could not be so much as $\frac{1}{10000}$ of a grain.

Another portion of this residual liquid being mixed with sulphate of soda, was not in the least altered, showing that the liquid contained no sensible portion of barytes. Thus it appears, that the barytes from 13·25 grains of chloride of barium, or 15·5 grains of muriate of barytes, just saturate the sulphuric acid in 18·125 grains of sulphate of zinc. Hence, this acid just weighs 5 grains.

We see therefore, that in neutral sulphate of zinc, 5·25 parts of the oxide are combined with 5 parts of the acid; which was the thing to be proved. These two constituents added together make 10·25, which subtracted from 18·125 leave 7·875 for the quantity of water of crystallization. It will appear afterwards that this is equivalent to 7 atoms of water. Sulphate of zinc in crystals, then, is composed of

1 atom sulphuric acid	5
1 atom oxide of zinc	5·25
7 atoms water .	7·875
	18·125

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So that 18·125 is the weight of an integrant particle of the crystallized salt. It was the knowledge of this that induced me to make choice of 18·125 grains of the salt. My first experiments were made upon a much larger quantity; but I have often repeated them with 18·125 grains, and obtained the result just stated.

If the solution of neutral sulphate of zinc be concentrated too much, it deposites, while still hot, an opaque crust upon the bottom of the vessel. This crust is very white, not so soluble in water as the crystals, and has not the least appearance of crystallization. It is neutral, though it reddens vegetable blues like the preceding salt; and being analysed in the same way as the crystallized sulphate, was found composed of White vitriol.

1 atom sulphuric acid	5
1 atom oxide of zinc	5·25
3 atoms water .	3·375
	13·625

So that an integrant particle of it weighs 13·625, and it differs from the crystals in containing only 3 atoms of water, instead of seven.

The white vitriol of the Germans consists of this second salt, while the sulphate of zinc manufactured in Great Britain consists of the former. The German white vitriol contains 24·77

per cent. of water, while the British sulphate of zinc contains 43·44 per cent.

2. CARBONATE OF ZINC.

Of carbonate of zinc.

One of the experiments related while giving the analysis of sulphate of zinc, is sufficient to show the proportion of carbonic acid, which combines with 5·25 parts of oxide of zinc. For 18·125 grains of sulphate of zinc, when decomposed by carbonate of soda, yielded a precipitate which, after being well washed and dried in the temperature of 212°, weighed 8 grains, and when exposed to a red heat, was reduced to 5·25 grains. These 8 grains were carbonate of zinc. The carbonic acid was dissipated by the red heat, and the oxide remained pure. We see that 5·25 of oxide of zinc are converted into carbonate by uniting with 2·75 grains of carbonic acid.

When carbonate of zinc is dried in the open air, without exposure to any artificial heat, I have obtained it composed as follows :

1 atom carbonic acid	2·75
1 atom oxide of zinc	5·25
2 atoms water	2·25
	10·25

so that an integrant particle of it weighs 10·25. But the water is very easily dissipated—indeed,

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so much so, that it is not easy to dry this carbonate without sustaining at least a partial loss of the water. But I have more than once succeeded in getting it with the exact atomic proportions. The carbonate of zinc occurs in the mineral kingdom, sometimes anhydrous, and sometimes containing 1 atom of water.

3. ARSENIATE OF ZINC.

Of arseniate of zinc.

This salt was obtained by the following process: 18·125 grains of the crystallized sulphate of zinc, and 20·75 grains of arseniate of soda were dissolved in separate portions of distilled water, and the two solutions, after being well mixed, were evaporated to dryness, and the dry mass digested in distilled water. A double decomposition took place, and arseniate of zinc separated in the state of a gelatinous looking matter. Being washed and dried in the open air, it constituted a white powder, weighing 26·5 grains. But when heated to redness, the weight was reduced to 13 grains. By a careful analysis of this salt, I found that its constituents were

1 atom arsenic acid	7·75
1 atom oxide of zinc	5·25
8 atoms water	9·0
	22·0

It would be easy to increase the number of these examples; but those given are sufficient

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to show that the atomic weight of oxide of zinc is 5·25, and that it is a compound of 4·25 zinc and 1 oxygen. And this being the only object in view, we need not at present proceed any farther.

SECT. II.

OF THE SPECIFIC GRAVITY OF OXYGEN GAS.

VARIOUS statements of the specific gravity of this gas have been published by different chemists. The following table exhibits those which have been generally considered the most to be depended on.

Specific gravities of oxygen gas.

1·114	.	Saussure, Ann. de Chim. LXXI. p. 269.
1·103	.	Biot and Arrago, Mem. de l'Institut. 1806, p. 320.
1·089	.	Allen and Pepys. Phil. Trans. 1807.
1·1117	.	Thomson, Annals of Philosophy, XVI. p. 163.
1·1026	.	Berzelius and Dulong, Ann. de Chim. et de Phys. XV. 386.

It would be impossible to decide which of these determinations deserves the preference. The experiments were all made with care, and no doubt, sufficient precautions were taken to have the gas in a state of purity. I shall therefore proceed to relate the attempts which I have made to determine the specific gravity of oxygen gas in quite a different way.

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A hundred grains of distilled zinc were put into a small retort, nearly filled with a mixture of one part of sulphuric acid, and four parts of distilled water. The beak of the retort was immediately plunged into a water trough, and the hydrogen gas evolved, was received into a graduated glass jar. After an interval of twenty *four* hours, when the whole zinc had been long dissolved, and the apparatus and its contents had acquired the temperature of the room, the hydrogen gas evolved was measured. The experiment was twice repeated, and the quantity of gas obtained in both cases was exactly the same. The thermometer during both experiments stood at 48°. The barometer, during the first experiment, was at 30 inches; but during the second, at 29·6 inches.

Method of determining the true specific gravity.

The volume of gas extricated in the first experiment was 137·08 cubic inches. In the second experiment, 100·18 grains of zinc were dissolved, and the volume of the gas extricated was 139·284 cubic inches. Now, when we make the necessary corrections for the height of the barometer, and the excess of zinc dissolved, the quantity of gas evolved is reduced to 137·08 cubic inches, as in the first experiment.

These two experiments give us the volume of hydrogen gas evolved during the solution of 100 grains of pure zinc in dilute sulphuric acid. But the gas was saturated with moisture at the

temperature of 48°. Had it been dry, its volume would have been only 135·4755 cubic inches.* At the temperature of 60°, 135·4755 cubic inches of gas become 138·7551 cubic inches.†

Thus it appears, that when 100 grains of zinc are dissolved in dilute sulphuric acid, the hydrogen gas evolved, supposing it perfectly dry, and supposing the barometer to stand at 30 inches, and the thermometer at 60°, amounts to 138·7551 cubic inches. Now, it has been demonstrated long ago, by Lavoisier, that the hydrogen gas thus evolved is derived from the water with which the sulphuric acid is diluted. A portion of this water is decomposed; its oxygen unites to the zinc, and converts it to an oxide, while the hydrogen makes its escape in the state of gas. The other constituent of the water, then, the oxygen has united to the zinc.

* Let p = pressure of atmosphere = 30 inches mercury.
f = elasticity of vapour, at 48° = 0·351 inches mercury.
x = volume of dry gas at 48°.
It has been shown by Dalton, that

$$\frac{p\,x}{p-f} = 137{\cdot}08.$$ Consequently

$$x = \frac{137{\cdot}08\,p - 137{\cdot}08\,f}{p}$$ and (substituting for p and f their values,)

$$x = \frac{4064{\cdot}265}{30} = 135{\cdot}4755 \text{ cubic inches.}$$

† From the experiments of Guy-Lussac we learn, that air and all gases increase in bulk $\frac{1}{480}$ part for every degree of Fahrenheit's thermometer. Hence at 60°, the volume of the gas is $\frac{12}{496}$ greater than at 48°. Now, $\frac{12}{496}$ of 135·4755 is 3·2796. Adding this to 135·4755, the volume becomes 138·7551 cubic inches.

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But if it were in the gaseous state, we know that its volume would be just half that of the hydrogen gas, or 69·3775 cubic inches. Thus it appears, that 100 grains of zinc, when converted into an oxide, unite with 69·3775 cubic inches of oxygen gas.

But from the facts established in the last section, it is evident, that 100 grains of zinc, when converted into an oxide, combine with 23·5294 grains of oxygen.* Hence, the weight of 69·3775 cubic inches of oxygen gas is 23·5294 grains. Consequently, 100 cubic inches weigh 33·915 grains.†

From the experiments of Sir George Shuckburgh Evelyn we learn, that 100 cubic inches of dry common air, under the same pressure, and at the same temperature, weigh 30·5 grains. And the specific gravity of common air being always reckoned unity, it is obvious that the specific gravity of oxygen gas must be 1·1111.‡

Thus we have obtained by a very simple process, which does not seem liable to any uncertainty, the very specific gravity of oxygen gas which Dr. Prout deduced from the supposition, that air is a mixture of four volumes azotic, and one volume oxygen gas; and which I adopted in

* 4·25 grains of zinc unite with 1 grain of oxygen, and 4·25 : 1 : : 100 : 23·5294.

† For 69·3775 : 23·5294 : : 100 : 33·915.

‡ For 30·5 : 33·915 : : 1 : 1·1111 nearly.

the last edition of my System of Chemistry, and in my Essay on the Specific Gravity of the Gases. If we compare the table at the begining of this section, with the specific gravity now found, we will perceive the results of the different experimenters as follows :—

Saussure's, too high by . .	$\frac{1}{570}$th part.
Biot and Arago's, too low by .	$\frac{1}{139}$th part.
Allen and Pepys's, too low by .	$\frac{1}{53}$d part.
Thomson's, too high by . .	$\frac{1}{1832}$d part.
Berzelius and Dulong's, too low by	$\frac{1}{130}$th part.

There seems no reason to doubt that Biot and Arago, and Allen and Pepys, took the specific gravity of oxygen gas standing over water, and consequently saturated with moisture. Let us suppose the temperature at which their experiments were made to have been 60°, and let us see what influence the presence of moisture must have had upon the specific gravity of their gas.

Let p=pressure of the atmosphere, suppose 30 in. mercury.
f=elasticity of vapour at 60°.=0·524 inch mercury.
a=sp. gr. of dry oxygen gas=1·1111.
b=sp. gr. of vapour at 60°.=0.00772.
x=sp. gr. of moist oxygen gas at 60°.

It is well known that

$$x = \frac{p-f}{} (a + b) = 1{\cdot}0992.$$

This is nearly the mean between the results of

Biot and Arago, and Allen and Pepys;—Saussure's errors and my own, being in excess, can only be explained by a mistake in the weighing. My own, indeed, is accurate as far as my balance could enable me to go. The quantity of oxygen gas weighed, amounted to 20 grains, and the smallest weight I used was $\frac{1}{100}$th of a grain; consequently, I could only estimate the weight within $\frac{1}{2000}$th part: the three first decimal places I could depend on, but not upon the fourth; accordingly the fourth decimal place was too high.

SECT. III.

OF THE SPECIFIC GRAVITY OF HYDROGEN GAS.

Method of determining the specific gravity of hydrogen gas.

I GOT a thin glass flask blown, with a flat bottom and a narrow cylindrical mouth, into which the extremity of a bent glass tube was ground, so as to fit it accurately. The capacity of the flask was about 18 cubic inches; the tube was 18 inches long, and the diameter of its interior cavity about the fifth of an inch. Its two extremities were bent nearly at right angles with the body, and turned different ways as here represented; *a* being the end which was ground into the mouth of the flask. The whole



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length of this tube was filled with small fragments of fused muriate of lime, except the two extremities, which were stuffed full of amianthus, in order to keep the muriate of lime in its place. This flask was nearly filled with a mixture of sulphuric acid and distilled water, in the proportion of about four parts of the latter to one part of the former. It was accurately weighed by means of an excellent balance, and the weight of the tube with the muriate of lime, was also separately determined. I then introduced into the flask, as rapidly as possible, a known weight of distilled zinc, in fragments; the tube with the muriate of lime was fixed in its mouth; and it was immediately plunged up to the neck in a large trough of water of the temperature of 48°, and left in that situation till the zinc was all dissolved. The flask was then wiped dry, put again in the balance, and the loss of weight which it had sustained was ascertained;—at the same time, the augmentation of weight of the tube with the muriate of lime was determined.

The object of this experiment was to ascertain the weight of a given volume of hydrogen gas; for the experiments related in the last section give us the volume of hydrogen gas evolved during the solution of a given weight of zinc. It was attended with so many unforeseen difficulties, that I was obliged to repeat it ten times before I became aware of all the precautions

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necessary to ensure success. Unless the gas be extricated very slowly, the muriate of lime does not dry it sufficiently—indeed, I was never able to free it completely from moisture; but a very simple calculation gave me the weight of the vapour which still adhered to it. The temperature of the liquid should be kept as low as possible, not merely to moderate the fermentation, but to avoid the risk of sulphuric acid escaping along with the gas. When the flask was left in the air, the temperature continued to rise for more than an hour after the experiment began. In one experiment it rose from 50° to 87°, in another, from 48° to 81°: the greater the quantity of zinc dissolved, the more accurate (cæteris paribus) was the experiment; but the quantity was unluckily very much limited by the small size of the flask.

It will be sufficient if I relate one experiment, during which, all the precautions that I could think of were taken; and which, I have reason to believe, was very nearly accurate.

The quantity of zinc dissolved was 143 grains —the effervescence continued for 24 hours—the temperature never rose higher than 49°—the barometer stood at 30·1 inches, and the thermometer at 49°—the loss of weight was 4·3 grains.

It will be, perhaps, more perspicuous, if we suppose that 100 grains of zinc only were dissolved. On that supposition, the loss of weight

sustained was 3 grains, and the tube containing the muriate of lime, had increased in weight 0·163 grains.

From the experiments related in the last section, it follows, that the volume of hydrogen gas given out during the solution of 100 grains of zinc, supposing the barometer to stand at 30·1 inches, and the thermometer at 49°, amounts to 136·88 cubic inches.

The specific gravity of vapour at 49°, under a pressure of 30·1 inches of mercury, is 0·00533; and the weight of the vapour contained in 136·88 cubic inches of moist gas, is 0·00533 × 136·88 × 0·305 gr.=0·2225 grain; but the moisture retained by the muriate of lime was only 0·163 grain. It is obvious from this, that the hydrogen still retained 0·059 grain of moisture.

If from the weight lost, amounting to 3 grains, we subtract this 0·059 grain for moisture, the remainder, amounting to 2·941 grains, gives the true weight of the hydrogen gas exhaled, supposing it perfectly dry. Now, from the experiments related in the last section, we know that the volume of this gas, under the pressure of 30 inches of mercury, and at the temperature of 60°, is 138·7551 cubic inches.

Oxygen gas just sixteen times heavier than hydrogen gas.

Thus it appears, that 138·7551 cubic inches of dry hydrogen gas (barometer 30 inches, thermometer 60°) weigh 2·941 grains: consequently, 100 cubic inches must weigh 2·119 grains. But

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we have seen in the last section, that 100 cubic inches of oxygen gas weigh 33·915 grains; now

2·119 : 33·915 : : 1 : 16·005.

This approaches so nearly the ratio of 1 : 16, that it leaves no doubt that the specific gravity of oxygen gas is exactly 16 times greater than that of hydrogen gas. Consequently, the specific gravity of hydrogen gas is $\frac{1}{16}$, or 0·0694; or exactly the specific gravity already deduced by Dr. Prout, from other considerations, and which I obtained experimentally, as may be seen in my Essay on the Specific Gravity of Gases.

That the proportion between the specific gravities of oxygen and hydrogen gases, is that of 16 : 1, is farther confirmed by an experiment of Berzelius and Dulong. They made dry hydrogen gas pass through a determinate weight of oxide of copper, heated to redness. The water thus formed was collected by means of dry chloride of calcium. The loss of weight sustained by the oxide of copper gave the weight of the oxygen in the water, while the weight of the hydrogen was denoted by the difference between the weight of the water and the oxygen: the mean of three trials gave the oxygen 889, and the hydrogen 111. Now 111 : 889 : : 1 : 8·009; and as water is a compound of 2 volumes hydrogen to 1 of oxygen, it follows, that the

specific gravity of hydrogen is to that of oxygen gas as 1 : 16·018.*

In my experiment, the oxygen was more than 16 times heavier than the hydrogen gas by $\frac{1}{3000}$th part—in that of Berzelius and Dulong it was a little more. The mean of both (which must come very near the truth) gives us the specific gravity of hydrogen to that of oxygen gas, as 1 : 16·011. That the true specific gravity of oxygen gas is 1·1111, will be shown in the fifth chapter of this work.†

The following table exhibits the most recent specific gravities of hydrogen gas obtained by experiment:

SP. GR. OF HYDROGEN GAS.	
0·0732	Biot and Arago.
0·0694	Thomson.
0·0688	Berzelius and Dulong.

It is obvious, when we compare these with the above found specific gravity of hydrogen gas, which must be exceedingly near the truth, that

* Ann. de Chim. et de Phys. xv. 389.

† I ought to mention that the weight of my flask filled with the dilute sulphuric acid and zinc, was about 3000 grains, and that of the tube filled with muriate of lime, about 1000 grains. My scales, loaded with double that weight, turned sensibly with $\frac{1}{200}$th of a grain. Hence, I consider myself as certain of the weight of the hydrogen gas to as many decimal places as I have given in the text. I weighed so as to make myself sure of the accuracy within $\frac{1}{100}$th of a grain:—Berzelius and Dulong determined the composition of water by an experiment nearly similar. Their result does not tally exactly with mine, nor can I institute a comparison, because they do not state the delicacy of their balance.

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Biot and Arago's is too high by $\frac{1}{18}$th part, Berzelius and Dulong's too low by $\frac{1}{113}$th part,—while my results, owing probably to a fortunate accident, are, as far as they go, quite correct.

Composition of water.

Water being a compound of 1 volume of oxygen gas, and 2 volumes of hydrogen gas, it is obvious, that it is composed of 8 parts, by weight, of oxygen, and 1 part of hydrogen. There can be no doubt that water is a neutral compound, and that it consists of an atom of oxygen united to a determinate atomic quantity of hydrogen; —but chemists are not yet quite agreed whether the hydrogen be 1 atom or 2 atoms. Sir H. Davy and Professor Berzelius consider the hydrogen as amounting to two atoms, because there are 2 volumes of it united to 1 volume of oxygen;—for they consider the volumes of these gaseous bodies as representing atoms. On the other hand, Mr. Dalton, Dr. Wollaston, Dr. Prout, and indeed by far the greater number of chemists, consider water as a compound of 1 atom oxygen, and 1 atom hydrogen, founding their opinion upon the well known fact, that these two gases cannot be directly united in any other proportions than those which exist in water.

If water contain only 1 atom of hydrogen, the atomic weight of this substance is obviously $\frac{1}{8}$th of that of oxygen, or 0·125; but if that liquid contain 2 atoms of hydrogen, then the atomic weight of hydrogen is only 0·0625.

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It is of no great consequence which of these opinions be adopted; yet if we take a view of the various compounds into which hydrogen enters, we can have little hesitation in fixing upon 0·125 for its atomic weight. A few of these compounds may be noticed in this place. The evidence of the facts here stated will be laid before the reader in the subsequent chapters of this work.

Atom of hydrogen weighs 0·125.

1. It is now known that oxygen and hydrogen unite in two proportions. Water contains the smallest quantity, while the deutoxide of hydrogen, discovered by Thenard, contains the greatest quantity of oxygen. The composition of these bodies is as follows:

	OXYGEN.		HYDROGEN.
Water consists of .	1	+	0·125
Deutoxide of hydrogen of	2	+	0·125

According to this way of stating the constituents, water is a compound of 1 atom oxygen, and 1 atom hydrogen; and the deutoxide of 2 atoms oxygen and 1 atom hydrogen. But if we state the constituents according to Berzelius's views,

	OXYGEN.		HYDROGEN.	
Water consists of	1	+	0·0625 × 2	or 2 atoms.
Deutoxide of .	1	+	0·0625	or 1 atom.

Or, water is a compound of 1 atom oxygen and 2 atoms hydrogen; and the deutoxide of 1 atom oxygen and 1 atom hydrogen. Now, would it

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not be a singular anomaly, if water, which is decomposed with considerable difficulty, should consist of 1 atom oxygen united to 2 atoms hydrogen, while the deutoxide, which parts with half its oxygen very readily, consists of 1 atom of oxygen united to 1 atom of hydrogen. This is not the case with other compounds. Bisulphate of potash may be deprived of half its sulphuric acid by exposure to a strong red heat; but the other half (which constitutes with potash the neutral compound) resists the highest temperature which we can apply.

2. Hydrogen unites with azote, carbon, phosphorus, and sulphur, as well as with oxygen, and with some of these bodies it unites in more than one proportion. But with none of these bodies does it ever combine in a smaller proportion than 0·125. Now, it would be a most extraordinary phenomenon, if never less than two atoms of this substance were to unite with an atom of other bodies. The following table exhibits the composition of a variety of bodies containing hydrogen.

			HYDROGEN.
Ammonia, composed of	1·75	azote	+ 0·125 × 3
Olefiant gas . . .	0·75	carbon	+ 0·125
Carburetted hydrogen .	0·75	———	+ 0·125 × 2
Phosphuretted hydrogen .	1·5	phosphorus	+ 0·125
Bihydroguret of phosphorus	1·5	———	+ 0·125 × 2
Sulphuretted hydrogen .	2	sulphur	+ 0·125

1·75, 0·75, 1·5, and 2 represent the atomic

weights of azote, carbon, phosphorus, and sulphur respectively, on the supposition that an atom of oxygen weighs unity. It is obvious from the table, that 0·125 hydrogen is the smallest quantity of hydrogen that unites with an atom of azote, carbon, phosphorus, or sulphur. Now, if 0·0625 were the atomic weight of hydrogen, how comes it that it never unites to any of these bodies in so small a quantity?

But if 0·125 be the atomic weight of hydrogen and 1 of oxygen, since water is a compound of 1 oxygen and 0·125 hydrogen, and is at the same time a compound of 1 volume oxygen and 2 volumes hydrogen gases, it follows as a consequence, that a volume of oxygen contains twice as many atoms as a volume of hydrogen. So that if we represent an atom of hydrogen by a volume, we must represent an atom of oxygen by half a volume.

It is obvious that the weight of an integrant particle of water is 1·125; nor is this weight altered, whether we consider it as a compound of 1 atom oxygen and 1 atom hydrogen, or of 1 atom oxygen and 2 atoms hydrogen. For on either supposition the atomic quantity of hydrogen must be represented by 0·125.

CHAP. IV.

OF THE ATOMIC WEIGHTS AND SPECIFIC GRAVITIES OF CHLORINE AND IODINE.

These two substances resemble each other in so many respects, that they ought to be classed together. Their analogy with oxygen is also very striking; though they differ likewise in some circumstances; the most remarkable of which is the property that they have of uniting with oxygen, and constituting with it an acid very similar in many respects to the nitric. I shall treat of each of these bodies in a distinct section.

SECT. I.

OF THE ATOMIC WEIGHT OF CHLORINE, AND THE SPECIFIC GRAVITY OF CHLORINE GAS.

It has been demonstrated, that muriatic acid gas is a compound of equal volumes of chlorine gas and hydrogen gas, united together without any change of bulk. Hence, the knowledge of the specific gravity of dry chlorine gas at the temperature of 60°, and when the barometer stands at 30 inches, will give us the ratio be-

tween the atomic weights of chlorine and hydrogen.

Specific gravity of chlorine gas.

Now, I took the specific gravity of this gas three times successively, and found it always 1·500.* Many other considerations lead to the conclusion that this is very near the truth. Of these it may be sufficient to mention the following:

1. The specific gravity of muriatic acid gas was found by me from an average of three experiments, to be 1·284366. Now, the specific gravity of this gas is a mean between that of chlorine and hydrogen gases. Let

x = sp. gr. of chlorine gas
a = sp. gr. of hydrogen gas

We have $\frac{x+a}{2} = 1{\cdot}284366$. Consequently

$$x = 2{\cdot}568733 - 0{\cdot}0694 = 2{\cdot}499333.$$

Now, 2·499333 is only $\frac{1}{3731}$ part less than 2·5. This is a coincidence between the two experiments as near as the nature of the apparatus employed will admit of.

2. Gay-Lussac, in a table inserted in the first volume of the *Annales de Chimie et de Physique*, states the specific gravity of chlorine gas to be 2·470. Now, if his experiments were made with gas prepared over water, as was undoubtedly the case, his result approaches very nearly to mine, if we estimate the specific gravity of the

* Annals of Philosophy, xvi. 169.

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dry gas, as will be obvious from the following simple calculation. Let

x = sp. gr. of dry chlorine gas
a = sp. gr. of vapour at $60^0 = 0{\cdot}00772$
p = 30 inches mercury
f = elasticity of vapour at $60^0 = 0{\cdot}524$

then

$$\frac{p-f}{p}(x+a) = 2{\cdot}47$$

The solution of this equation gives us $x = 2{\cdot}507$. Thus it appears, that if Gay-Lussac made his experiments at the temperature of 60°, the true specific gravity of his chlorine gas was 2·507. If the temperature (as is most likely) was a few degrees above 60°, then the true specific gravity of the gas would be exactly 2·5, and his experiments would coincide with my own.

We may therefore, without hesitation, adopt 2·5 as the true specific gravity of dry and pure chlorine gas.

Atom of chlorine weighs 4·5.

As muriatic acid is a compound of equal volumes of chlorine gas and hydrogen gas, and as these gases unite in no other proportions, we cannot hesitate to consider muriatic acid as a compound of 1 atom chlorine and 1 atom hydrogen. The atom of chlorine, therefore, must bear the same relation to the atom of hydrogen, that the specific gravity of chlorine gas does to that of hydrogen gas. But chlorine gas is 36 times heavier than hydrogen gas; for 0·0694 ×

36 = 2·5. The atomic weight of hydrogen is 0·125. Consequently that of chlorine is 0·125 × 36 = 4·5.

It is obvious too, that the volume of chlorine gas bears the same relation to the atom of chlorine that the volume of hydrogen gas does to the atom of hydrogen. If, therefore, we may substitute a volume of hydrogen gas for an atom, we may, in like manner, substitute the volume of chlorine gas for the atom of chlorine.

Proved from the chloride of copper,

I. It is easy to show by simple and decisive experiments, that 4·5 is the true atomic weight of chlorine. Of these, it may be worth while to state one or two in this place.

1. An atom of copper, as will appear hereafter, weighs 4; an integrant particle of suboxide of copper weighs 9; and an integrant particle of black oxide, 5. Each of these oxides combines with muriatic acid. The protomuriate of copper is white, and the permuriate green. Both of these muriates crystallize, and both contain water of crystallization. When the muriates of copper are heated without the contact of air, they not only lose their water of crystallization; but the oxide of copper, and the muriatic acid lose respectively, the oxygen and the hydrogen which they contain. These two constituents unite together, and make their escape in the form of water, leaving behind a compound of chlorine and copper. In the suboxide

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of copper there are two atoms of copper united to one atom of oxygen, and the protomuriate of copper is a compound of one integrant particle of muriatic acid, and two integrant particles of suboxide of copper, and the permuriate of one atom muriatic acid, and one atom black oxide of copper. Now, that this is the true constitution of these two salts, I have ascertained by a careful analysis of them.

These facts being understood, we are prepared for examining the chlorides of copper. Of these chlorides, there are two—the *protochloride*, obtained by heating the protomuriate in a close vessel; and the *deutochloride*, formed when the permuriate is treated in the same way.

Now, Dr. Davy analyzed the protochloride of copper, and found it a compound of

Copper	8
Chlorine	4·5
	12·5 *

Two atoms of copper weighing eight, 4·5 must represent the weight of an atom of chlorine.

I dissolved 5 grains of black oxide of copper in muriatic acid, and evaporated the solution to dryness. The chloride of copper was obtained in the state of a brownish yellow powder, and it weighed exactly 8·5 grains. Now, 5 grains of

* Phil. Trans. 1812. p. 170.

black oxide are equivalent to 4 grains of metallic copper. So that the chloride was a compound of

Copper	4
Chlorine	4·5
	8·5

4·5 is evidently one atom of chlorine, and 4 one atom of copper. In this chloride one atom of copper is united with one atom of chlorine.

Thus it appears, that an atom of chlorine unites with either one atom or two atoms of copper; and that an atom of chlorine weighs exactly 4·5.

The chloride of mercury,

2. It will be shown hereafter, that an atom of mercury weighs 25. Now, mercury, like copper, combines with two proportions of chlorine, forming a *protochloride*, usually called *calomel*, and a *deutochloride*, usually called *corrosive sublimate*.

Calomel is composed of

Mercury	25
Chlorine	4·5
	29·5

and corrosive sublimate of

Mercury	25
Chlorine	9
	34*

* See Annals of Philosophy, (second series) II. 127.

We see that the first is a compound of one atom mercury and one atom chlorine, and the second of one atom mercury and two atoms chlorine. Here, as well as with copper, 4·5 represents exactly the weight of an atom of chlorine.

And the chloride of silver.

3. Silver is a metal, the atomic weight of which is 13·75. Dissolve 13·75 grains of pure silver in nitric acid; evaporate the solution gently to dryness, and re-dissolve the nitrate of silver in water; precipitate the silver by pouring into the liquid a solution of 7·5 grains of pure and dry common salt; collect the precipitate, wash it well, and fuse it on a piece of glass:—if the experiment be properly conducted, the chloride of silver, thus obtained, will weigh 18·25 grains.* Now, it contains exactly 13·75 grains of silver. Hence, it is composed of

Silver	13·75
Chlorine	4·5
	18·25

or in this compound, an atom of silver is combined with an atom of chlorine.

In all these examples, the atomic weight of chlorine is exactly 4·5.

4. It has been long known, that when chlo-

* The chloride of silver, while on the filter, must be washed with distilled water. This water should be very slightly acidulated with nitric acid. For want of this precaution, I was long unable to obtain the exact weight of chloride. The reason is, that distilled water often contains ammonia, which dissolves a little chloride.

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Decahydrate of chlorine.

rine gas is collected over water in temperatures below 40°, a number of green coloured crystals form. These crystals were considered as solid chlorine, till Sir. H. Davy showed, in 1810, that they were a compound of chlorine and water, or a hydrate of chlorine. During the severe winter of 1822-3, this hydrate was analyzed by Mr. Faraday, who found it to be composed of

Chlorine	27·7 or	4·5
Water	72.3	11·745
	100·0 *	

11·745 exceeds 10 atoms of water by 0·495, which is rather more than ½ of an atom. It was doubtless hygrometrical water. These crystals, then, must be considered as constituting a decahydrate of chlorine composed of

10 atoms water	11·25
1 atom chlorine	4·5
	15·75

Chlorine and oxygen.

II. Chlorine, according to the experiments of Sir H. Davy and Count Von Stadion, combines with no fewer than five proportions of oxygen, forming three oxides and two acids. The composition of these different compounds, which, with the exception of chloric acid, have been analyzed only by Davy and Von Stadion, is as follows:

* Annals of Philosophy, (second series) V. 304.

	CHLORINE.		OXYGEN.	ATOMIC WEIGHT.
1. Protoxide of chlorine.	1 atom	+	1 atom	5·5
2. Tritoxide of chlorine	1	+	3	7·5
3. Quadroxide of chlorine	1	+	4	8·5
4. Chloric acid	1	+	5	9·5
5. Perchloric acid	1	+	7	11·5 *

III. Hydrogen and chlorine, as far as we know at present, unite in only one proportion, constituting muriatic acid, the atomic weight of which is 4·625. Chlorine and hydrogen.

This acid is one of the most active and corrosive with which we are acquainted. It is very much used in chemical analyses, and indeed is altogether indispensable in a laboratory. When pure, it is a gas, the specific gravity of which is 1·28472, being exactly the mean between the specific gravities of chlorine gas and hydrogen gas.

I find that at the temperature of 69°, one cubic inch of water is capable of absorbing 417·822 cubic inches of muriatic acid gas. The temperature of the liquid augments considerably, and its volume, when cooled down to the temperature of the air, is 1·3433 cubic inch. It is obvious from this, that 100 grains of acid of this strength contain 103 cubic inches of acid gas; and a cubic inch of this acid contains 311·04146 Liquid muriatic acid.

* The protoxide was analyzed by Davy, the tritoxide by Von Stadion, the quadroxide by Davy. It has not been ascertained whether or not the two last constitute really distinct substances. Chloric acid was first analyzed by Chenevix, and more correctly by Berzelius. Perchloric acid was discovered and analyzed by Von Stadion.

cubic inches of acid gas. Acid of this strength has a specific gravity of 1·1958, and I find, by saturating it with calcareous spar, that it contains 40·39 per cent. of real acid, united with 59·61 of water. In winter I have obtained muriatic acid of as high a specific gravity as 1·212.

All the tables hitherto published, exhibiting the strength of muriatic acid of various specific gravities, are very erroneous; because they were constructed upon inaccurate data. I conceive, therefore, that it will be worth while to exhibit an accurate table of the specific gravity of this acid of determinate strengths. My method of proceeding was to saturate a given weight of the acid with calcareous spar. Every 6·25 grains of calcareous spar dissolved, indicated the presence of 4·625 grains of muriatic acid. Knowing the exact strength of one particular acid, it was easy, by the addition of determinate weights of water, to form acid of any inferior strength wanted. I shall exhibit the specific gravity of combinations of one atom of muriatic acid, with a determinate number of atoms of water. The strongest acid I could form, at the time that I was employed in these experiments, was a compound of one atom acid, and six atoms water. Its specific gravity was 1·203, and it contained, of course, 40·659 per cent. of real acid. This acid is so volatile, that it can with difficulty be preserved in warm weather. Indeed it frequently

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forces out the stopper, while a quantity of muriatic acid gas makes its escape.

TABLE EXHIBITING THE SPECIFIC GRAVITY OF MURIATIC ACID OF DETERMINATE STRENGTHS.

Atoms of Acid.	Atoms of Water.	Acid in 100	Specific Gravity.
1	6	40·659	1·203
1	7	37·000	1·179
1	8	33·945	1·162
1	9	31·346	1·149
1	10	29·134	1·139
1	11	27·206	1·1285
1	12	25·517	1·1197
1	13	24·026	1·1127
1	14	22·700	1·1060
1	15	21·512	1·1008
1	16	20·442	1·0960
1	17	19·474	1·0902
1	18	18·590	1·0860
1	19	17·790	1·0820
1	20	17·051	1·0780

Muriatic acid, composed of 1 atom acid, and 16 atoms water, or that which contains 20·442 per cent. of real acid, seems to be the most intimate combination of acid and water. For its boiling point is a maximum, being 232°, according to Dalton; while acid either weaker or stronger than this boils at a lower temperature. Indeed the boiling point of acid of the specific gravity 1·203 is not higher than 107°.

The muriates, or the salts formed by the combination of muriatic acid with the different bases, deserve the particular attention of chemists in many points of view. I shall devote a separate

chapter to the investigation of their constitution in a subsequent part of this work.

SECT. II.

OF THE ATOMIC WEIGHT OF IODINE.

The properties of iodine were investigated with such sagacity and success by M. Guy-Lussac and Sir H. Davy, that succeeding experimenters have had but little to add to the result of their investigations. I shall mention here the few particulars that I have had an opportunity of observing.

Specific gravity of iodine.

1. Gay-Lussac states the specific gravity of iodine to be 4·948; but I have reason to believe that this estimate is too high. I sublimed some iodine by exposing it in an eight ounce phial to a very low heat. By this method it may be obtained in pretty large octahedral crystals, approaching to the shape of the primitive form of sulphur. A number of these crystals were picked out, and their specific gravity taken. I found it 3·0844. The specific gravity of iodine, as originally prepared without any purification, is somewhat less, being only 2·915. This difference is owing to the presence of a very small quantity of water. The specific gravity of distilled water saturated with iodine is 1·00021— a sufficient proof of the

small quantity of this substance which water is capable of dissolving.

2. Gay-Lussac found that when iodine and zinc are heated together in a vessel hermetically sealed, and containing a sufficient quantity of water, a colourless solution is obtained, consisting of hydriodate of zinc. In this case he found that 100 parts of iodine combine with 26·225 parts of zinc.* Now 26·225 : 100 : : 4·25 (an atom of zinc) : 16·20. According to this experiment, 16·20 denotes the atomic weight of iodine. Gay-Lussac himself deduces from his experiment, that the atomic weight of iodine is 15·621; because he conceived that 26·225 of zinc combine with 6·402 oxygen, whereas the quantity of oxygen with which this weight of zinc combines, when oxydized, is only 6·170 parts.

This experiment of Gay-Lussac was repeated by Dr. Prout, who found that 50 parts of iodine combine with 12·9 parts of zinc.† According to this experiment, the atomic weight of iodine turns out 16·473, which is a little higher than that stated by Gay-Lussac.

3. I have repeated this experiment a good many times, but I did not obtain constant results, partly from the difficulty of preventing the loss of some of the iodine, and partly because the zinc was never perfectly pure. I therefore had recourse to another method, which I shall

Method of determining the atom of iodine.

* Ann. de Chim. XCI. 24. † Annals of Philosophy, VI. 323.

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now explain. I formed a quantity of hydriodate of potash, and by a careful analysis, satisfied myself that it is composed of an atom of hydriodic acid, united to an atom of potash. When this salt is exposed to a pretty strong heat in close vessels, it gives out water, and is converted into iodide of potassium. After a variety of trials, I found that when 20·5 grains of this iodide of potassium are dissolved in a small quantity of distilled water, and the solution mixed with a solution of 20·75 grains of dry nitrate of lead, a double decomposition takes place: iodide of lead is precipitated, and the residual liquid is transparent and colourless, and neither altered by sulphate of soda, nor by nitrate of lead, showing that it contains no sensible quantity of oxide of lead, or hydriodic acid. The residual liquid being evaporated to dryness, furnished 12·75 grains of salt-petre. But 12·75 grains of salt-petre (as will be seen in the next chapter) contain 6 grains of potash, equivalent to 5 grains of potassium. Consequently, the 20·5 grains of iodide of potassium contained just 5 grains of potassium. The remainder consisted of iodine. From this it appears that iodide of potassium is a compound of

Iodide of potassium.

Potassium	5
Iodine	15·5
	20·5

5 being the atomic weight of potassium, and the iodide being a neutral compound, it is obvious that 15·5 must be the weight of an atom of iodine.

The above experiment was repeated, substituting 19·75 grains of iodide of zinc, for the 20·5 grains of iodide of potassium. When solutions, containing respectively 19·75 grains of iodide of zinc, and 20·75 of nitrate of lead, were mixed together, I found it necessary to evaporate the mixture to dryness by means of a very gentle heat. Water being poured upon the yellow residue, was digested on it for some time. It was then tested with sulphate of soda, and with nitrate of lead, without being in the least affected by either of these re-agents, showing that it contained no sensible quantity of lead, or of iodine. Unless the original mixture of the two salts be evaporated to dryness, sulphate of soda is very apt to indicate the presence of lead—and if the evaporation be carried too far, or too great a heat be applied to the residual matter, the water poured upon it will acquire a yellow colour, and will contain distinct traces of iodine. If this be avoided, the liquid will contain simply a solution of nitrate of zinc. Iodide of zinc.

From this experiment, which I have made several times successfully, it is obvious that 19·75 grains of iodide of zinc contain just an atom of iodine, or the quantity necessary to unite with

13 of lead, which exist in 20·75 of nitrate of lead. As the iodide of zinc is neutral, there must be present in it just an atom of zinc, which weighs 4·25. Thus it appears that dry iodide of zinc is composed of

Zinc	4·25
Iodine	15·5
	19·75

These experiments leave no doubt that the atom of iodine weighs 15·5. This is the number which Dr. Prout fixed upon, though from erroneous data.

It is obvious also from these experiments, that hydriodic acid is a compound of 1 atom iodine, and 1 atom hydrogen. For when hydriodate of zinc is heated sufficiently, it is converted into iodide of zinc. It is evident that the oxide of zinc by this treatment is deprived of its oxygen, and the hydriodic acid of its hydrogen. These two substances combine together, and fly off in the state of water. Consequently, the atoms of hydrogen in the acid must be just equal to the number of atoms of oxygen in the oxide. But oxide of zinc contains only one atom of oxygen; consequently hydriodic acid contains only one atom of hydrogen.

Hydriodic acid.

From the experiments of Gay-Lussac, which I have often repeated, we learn that when hydriodic acid gas is left in contact with mercury, the whole of its iodine is gradually absorbed, and

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its volume is reduced to one half, consisting of hydrogen gas. Here it is clear that hydriodic acid is a compound of equal volumes of iodine vapour and hydrogen gas, united together without any change of volume. A volume of iodine vapour, then, bears the same relation to an atom, that a volume of hydrogen gas does to an atom. But the specific gravity of hydrogen gas is obtained by multiplying its atomic weight by half the specific gravity of oxygen gas, or by 0·5555. For 0·125 + 0·5555 = 0·0694. It will be shown in the 7th chapter of this work that this law is general. Consequently, to obtain the specific gravity of iodine vapour, we have only to multiply 15·5 by 0·5555. The product is 8·6111, which is the true specific gravity of iodine vapour.

The specific gravity of hydriodic acid is a mean between that of iodine vapour and of hydrogen gas, or 4·34027.

The atomic weight of hydriodic acid is 15·625.

Iodic and chloriodic acids.

Iodine combines both with oxygen and with chlorine, and forms with the former iodic acid, and with the latter chloriodic acid. I have not myself made any experiments to determine the atomic weight of these acids; but from Gay-Lussac's experiments it is evident, that iodic acid is a compound of one atom iodine, and five atoms oxygen. It must therefore weigh 20·5.

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From the experiments of Sir H. Davy, I have little doubt that chloriodic acid is a compound of one atom iodine, and two atoms chlorine. Consequently, its atomic weight is 24·5.

CHAP. V.

OF THE ATOMIC WEIGHT OF AZOTE, AND THE SPECIFIC GRAVITY OF AZOTIC GAS.

I SHALL begin this chapter with an account of the experiments to determine the true specific gravity of azotic gas. The specific gravity of common air is always reckoned unity, and we have seen in the third chapter of this work, that the true specific gravity of oxygen gas is 1·111. Now, as air is a mixture of oxygen and azotic gases, it is obvious that, in order to obtain the true specific gravity of azotic gas we have only to determine by rigid experiments what is the true ratio between the volumes of oxygen and azotic gases in common air. Many experiments have been made upon this subject; but chemists do not seem to have employed the requisite precautions to ensure a successful result.

Composition of common air determined.

1. In order to have common air in a state of purity, I collected a quantity of it from above the middle of a green field, at some distance from all houses. The hydrogen gas, which was employed to remove the oxygen, was prepared from a mixture of purified zinc, and pure sulphuric acid diluted with distilled water. The retort in which the gas was extricated, was quite

filled with this mixture, and a portion of the hydrogen gas was allowed to escape, before I began to collect it for use. The eudiometrical experiments were made while the hydrogen gas was coming over, and it was taken for every experiment directly from the beak of the retort, and consequently, without standing any time in contact with water.

A mixture of 100 volumes of air, and 42 volumes of this pure hydrogen gas, was fired by an electric spark. The diminution of bulk in three successive experiments was precisely 60 volumes. Now, the volume of oxygen gas in the 100 parts of air employed is obviously $\frac{1}{3}$ of this diminution of bulk. But $\frac{1}{3}$ of 60 is 20. Thus it appears, that 100 volumes of air contain 20 volumes of oxygen gas. The remaining 80 volumes constitute the azotic gas of air. Air then is a mixture of

20 volumes oxygen gas
80 volumes azotic gas

100

or the 5th of the volume of common air is oxygen gas, and four-fifths azotic gas.

If we employ less than 42 volumes of hydrogen gas to 100 of air, the combustion is not complete. Thus, when a mixture of 100 volumes air and 40 volumes hydrogen is fired, the diminution of bulk amounts to 57 volumes, in-

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stead of 60. The third of 57 is only 19, showing that one volume of the oxygen gas present had escaped combustion. When the quantity of hydrogen gas is greater than 42 to the 100 of air, the diminution of volume somewhat exceeds the truth, and it goes on increasing till the volume of hydrogen gas is equal to that of the air, beyond which I did not think it worth while to carry the experiment. 50 volumes of air, and 50 of hydrogen gas, being mixed and fired, the diminution of bulk was 32 volumes. The third of this is 10·66̇. This would raise the bulk of oxygen gas in air to 21$\frac{1}{3}$ per cent. This diminution of the volume beyond the proper quantity seems to be owing to the formation of a small quantity of nitric acid or ammonia. The best proportions are 100 volumes air, and 42 volumes hydrogen gas; with these we always find the diminution of volume 60 indicating 20 per cent. of oxygen gas in air.

I likewise verified this analysis of air by means of phosphorus: 100 volumes of air were left standing for two days over mercury, with a stick of phosphorus immersed in them. The glass jar with the air was then removed to the water trough, and well washed, to deprive it of any phosphoric acid which might have a tendency to alter its volume. And to facilitate the action of the phosphorus, a little water was added, so that the air was saturated with moisture at the

temperature in which the experiments were made. The following table exhibits a view of the results of these experiments.

No of Experiments.	Volumes of air.	Height of Barom.	Height of Thermom.	Residue.	Height of Barom.	Height of Thermom.
		INCHES.	DEGREES.		INCHES.	DEGREES.
1	100	30·33	61·5	82	30·08	62
2	100	30·08	62	80	29·8	62
3	100	29·80	62	81	29·5	60·5
4	100	29·5	60·5	78	29·99	59·5
5	100	29·99	59·5	79·75	30·07	60
6	100	29·99	60	80	29·94	61
7	100	29·94	61	80	29·7	60·5
8	100	29·70	60	81	29·5	58·5
9	100	29·5	58·5	79·5	29·6	58
10	100	29·54	58	80	29·55	58

Before we can draw any consequence from these experiments, we must determine by calculation the volume of the residues, supposing them perfectly dry, and supposing the barometer at 30 inches, and the thermometer at 60°. The following table shows what these volumes are.

No. of Experiments.	Volumes of Air.	Volumes of Residue.	Ratios of vol. of Air.	Ditto of vol. of Residues.
1	98·953	80·08	100	80·927
2	97·984	77·648	100	79·246
3	97·051	78·130	100	80·504
4	96·457	76·714	100	79·532
5	98·352	78·543	100	79·851
6	98·217	78·232	100	79·652
7	97·889	77·698	100	79·374
8	97·253	78·551	100	80·770
9	97·018	77·462	100	79·843
10	97·236	77·816	100	80·028
Mean - - - - - - - - - -			100	79·9735

The last column shows the residue of dry gas,

from 100 volumes of dry air, supposing the barometer at 30 inches, and the thermometer at 60°. The mean of ten experiments gives the composition of dry air :

Azote	79·9735
Oxygen	20·0265
	100·0000

Now this is within $\frac{1}{1000}$ part of

Azote	80
Oxygen	20
	100

a degree of coincidence with the former experiments, as near as my method of proceeding enabled me to reach. It confirms very completely the preceding conclusions.

The proportion of the constituents of air in volume being thus known, it is easy to determine the specific gravity of azotic gas. Let $x =$ a volume of azotic gas, then

$$1{\cdot}1111\dot{} + 4x = 5 \quad \text{and}$$
$$x = \frac{3{\cdot}8888\dot{}}{4} = 0{\cdot}9722\dot{} = \text{specific gravity}$$

of azotic gas.*

* The specific gravity of oxygen and azotic gases might be deduced directly, from the known specific gravity of air; *viz.* 1·000, and the proportion of these two gases, *viz.* 80 azotic and 20 oxygen gas in 100 volumes of air, as Dr. Prout has already done, (Annals of Philosophy, VI. 322.)

Let the atom of oxygen = 1
azote = 1·75

Atomic weight of nitric acid determined,

2. I have been thus particular in determining the specific gravity of azote, because it is a necessary element in the investigation of its atomic weight. We shall now determine the atomic weight of nitric acid, which is known to be a compound of azote and oxygen; and it contains the greatest proportion of oxygen with which an atom of azote is capable of uniting. Nitric acid

Air is a compound of one atom of oxygen and two atoms azote; or of

Oxygen	1	or	22·22̇
Azote	3·5		77·77̇
			100

Let x = specific gravity of oxygen $22{\cdot}22\dot{} = a$

y = azotic gas $77{\cdot}77\dot{} = b$

then $\frac{x + 4y}{5} = 1$ and $x = 5 - 4y$

and $x : 4y :: a : b$ and $x = \frac{4ay}{b}$

Hence $5 - 4y = \frac{4ay}{b}$ and $y = \frac{5b}{4a + 4b} = 0{\cdot}9722\dot{}$

and $x = 5 - 4y = 5 - 3{\cdot}8888\dot{} = 1{\cdot}111\dot{1}$

I have thought it better to proceed as I have done in the text, because the atomic weight of azote is most easily deduced from the specific gravity of azotic gas.

Berzelius and Dulong, in their paper on the specific gravity of gases, give us the specific gravity of oxygen and azotic gases, as follows:

Oxygen	1·1026
Azotic	0·9760

Now, as air is a compound of 4 volumes azotic and 1 volume of oxygen gas, it is obvious that $\frac{1{\cdot}1026 + 0{\cdot}9760 \times 4}{5}$ = specific gravity of common air. If we resolve the equation, we find the specific gravity of common air not 1, as it ought to be, but 1·00132; showing that the specific gravities of oxygen and azotic gases, as determined by these chemists, cannot be correct.

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has the property of combining with the various bases, and of forming salts distinguished by the generic name of *nitrates*. Several of these nitrates contain no water of crystallization, but consist of the anhydrous acid united to the base; this is the case with nitrate of lead and nitrate of potash. I shall make use of nitrate of lead to determine the atomic weight of nitric acid.

From nitrate of lead,

It will be shown in a subsequent chapter, that the atom of lead weighs 13, and the atom of protoxide of lead, which constitutes the base of nitrate of lead, 14. This salt is neutral, and consequently consists of one atom of nitric acid united to one atom of protoxide of lead. It is white, opaque, has a strong lustre, and crystallizes in octahedrons. Sometimes it may contain a little water mechanically lodged between its plates; but this is not the case when it is properly crystallized; and it may be always rendered anhydrous by exposure for a few hours to a heat of 212°.

Sulphate of soda is a salt composed of one atom sulphuric acid, one atom soda, and ten atoms water:—but it is with great facility freed from its water of crystallization. A few days' exposure in a dry room is sufficient for the purpose; or we may place it in the vacuum of an air-pump, in a vessel raised an inch or two above a flat plate filled with sulphuric acid. Twenty-four hours of such a situation renders it quite

anhydrous; a moderate heat drives off the water of crystallization with great facility; and we may afterwards fuse it, to be absolutely certain that all traces of water are removed.

When this salt is anhydrous, it is composed of

1 atom sulphuric acid	=	5
1 atom soda	=	4
		9

so that nine grains of it contain exactly five grains of sulphuric acid.

The nature and constitution of these two salts being understood, we are prepared to investigate the weight of an integrant particle of nitric acid.

I took two small glass vessels, containing each a little distilled water; in the one, I dissolved 20·75 grains of pure nitrate of lead, and in the other, 9 grains of anhydrous sulphate of soda. These two solutions being mixed together, a double decomposition took place; the sulphuric acid and oxide of lead uniting together, and forming an insoluble sulphate of lead, which fell rapidly to the bottom, while the nitric acid and soda remained in solution in the colourless liquid. As soon as the sulphate of lead had left the liquid quite clear and transparent, a few drops of it were put into two different watch glasses; into one of these, I let fall a little of

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the solution of muriate of barytes, and into the other, a little of the solution of sulphate of soda. But no precipitation, or even opalescence, was produced by either of these re-agents; showing that the liquid contained no sensible quantity of sulphuric acid, or of oxide of lead.

From this experiment it follows, that the sulphuric acid in nine grains of anhydrous sulphate of soda, is just sufficient to saturate the oxide of lead in 20·75 grains of nitrate of lead; but nine grains of anhydrous sulphate of soda contain five grains of sulphuric acid, which requires just fourteen grains of protoxide of lead to saturate it. Accordingly, if the sulphate of lead precipitated be washed, collected, and dried, without any loss, it will be found to weigh exactly nineteen grains. Thus, it is proved, that 20·75 grains of nitrate of lead contain 14 grains of protoxide of lead. So that nitrate of lead is composed of

Protoxide of lead	14
Nitric acid	6·75
	20·75

The salt being neutral, and 14 denoting an integral particle of protoxide of lead, it is clear that the atomic weight of nitric acid is 6·75.

3. The importance of an accurate knowledge of the atomic weight of nitric acid is so great, And nitrate of silver.

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that it may not be amiss to give an equally rigid proof of what it really is, drawn from the composition of nitrate of silver, a salt very frequently employed in chemical analyses.

Nitrate of silver is a white transparent salt, which may be crystallized in beautiful rhomboids; but it most commonly assumes the form of thin plates, which have been compared to sword blades. It contains no water of crystallization, though sometimes a little may be mechanically lodged between the plates of the crystals. From this it is easily freed, by fusing it in a moderate heat, and keeping it for some time in that state. The small cylinders of it sold by apothecaries, under the name of *lunar caustic*, are quite anhydrous. But I have never met with them perfectly pure; they usually contain a little gold, which separates in flocks, when the cylinder of nitrate of silver is dissolved; and not uncommonly, other impurities (particularly nitre) are likewise present. For the experiment which I am going to relate, the salt must not only be anhydrous, but quite pure.

The atomic weight of silver, as will be shown hereafter, is 13·75, and an integrant particle of oxide of silver weighs 14·75. Consequently, if the atomic weight of nitric acid be 6·75, as we have found it to be from the analysis of nitrate of lead, the constituents of nitrate of silver must be

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Nitric acid	6·75
Oxide of silver	14·75
	21·5

When common salt is fused, it is converted into chloride of sodium, which is composed of

Chlorine	4·5
Sodium	3
	7·5

When 7·5 parts of chloride of sodium are dissolved in water, they combine with 1·125 of water, and are converted into muriate of soda, composed of

Muriatic acid	4·625
Soda .	4
	8·625

These facts being understood, we may proceed to the experiment. I dissolved 21·5 grains of fused nitrate of silver, and 7·5 grains of fused common salt, in separate portions of distilled water, and mixed the solutions. A double decomposition took place;—the muriatic acid and oxide of silver united together, and precipitated in the form of a heavy, white, curdy matter; while the nitric acid and the soda remained in solution, in the state of nitrate of soda. When

the precipitate had subsided, and left the supernatant liquid quite clear, a few drops of it were put into two separate watch glasses;—into the one a little nitrate of silver was let fall, and into the other a little common salt. The liquid was not precipitated nor rendered opalescent by either of these re-agents, showing, that it contained neither muriatic acid nor oxide of silver.

From this experiment we see, that the muriatic acid in 8·625 grains of muriate of soda, just saturates the oxide of silver in 21·5 grains of nitrate of silver. But 4·625 of muriatic acid require just 14·75 of oxide of silver for saturation. This is, of course, the quantity of oxide in 21·5 of fused nitrate of silver—the remainder, amounting to 6·75, must be nitric acid. Thus we have found the composition of nitrate of silver exactly agreeing with our hypothesis,—demonstrating that 6·75 is the atomic weight of nitric acid.

When the muriate of silver, obtained in the preceding experiment, is washed, dried, and fused, it is converted into chloride of silver; consequently,

4·625	muriatic acid become	4·5	chlorine.
14·75	oxide of silver become	13·75	silver.
19·375		18·25	

Hence, if it be collected without any loss, which

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is a difficult process, the weight, instead of being 19·375 grains, will only be 18·25 grains.

From these two experiments, we are entitled to affirm, that the atomic weight of nitric acid is 6·75.

4. To demonstrate the true composition of nitric acid, I shall employ nitrate of potash. Analysis of nitre

This salt, when pure, contains no water of crystallization; but a little water is often mechanically lodged between the plates of the crystals. This water is easily dissipated by keeping the salt for some time in a moderate heat; or simply, by bringing it into fusion. The salt upon which the following experiments were made was pure, and perfectly anhydrous.

There is a particular temperature, higher than 600°, but I do not know how much, in which, if saltpetre be kept, it allows a certain portion of oxygen gas to escape and no more. When 127½ grains of nitre are kept in this temperature during the requisite time, there are extricated 29½ cubic inches of pure oxygen gas; the weight of the nitre is reduced to 117½ grains, and the salt is no longer *nitrate of potash*, but *nitrite of potash*; for when acetic acid is poured on it, red fumes are extricated, which is not the case with saltpetre. Now, it will be shown in a subsequent part of this chapter, that the atomic weight of *nitrous acid* (the acid in nitrite of potash) is 5·75. It will appear immediately, that nitric acid is com- By heat;

posed of 5 oxygen and 1·75 azote; consequently, 29⅛ cubic inches, weighing 10 grains, is the fifth part of the whole oxygen in 127½ grains of nitre. This makes the whole oxygen in 127½ grains of nitre to amount to 147·5 cubic inches, or 50 grains.

But though I have made many attempts to obtain the whole oxygen and azote in a given weight of nitre, in the gaseous state, I have only met with partial success.

I never succeeded in decomposing nitre in a porcelain retort, without destroying the vessel before the decomposition was completed. The potash, as it is evolved, acts so powerfully upon the vessel, at the high temperature which must be kept up, that it soon makes its way through it, and enables the gaseous products to escape.

When the nitre was mixed with twice its weight of siliceous sand, I decomposed it with facility in a common stone-ware retort; but the retort, in the high temperature to which it was necessary to raise it, was pervious to the air. This prevented me from determining with precision the proportion between the volumes of the two gases evolved—and Wedgewood retorts, though air tight, always cracked before the process was completed. In general, the gaseous products consisted of

1 volume azotic gas
2·3 volumes oxygen gas

And the proportion of azotic gas was always found to increase with the length of the process. I came nearer the truth with a small quantity of nitre than with a large quanity—but I was never able to obtain the whole volume of gas which nitre is capable of giving out.

I next tried to decompose nitre by heating it, mixed with charcoal powder, in a copper tube. The tube was heated to redness, and the gaseous products collected over mercury. By this process, I obtained a greater volume of gas than nitre itself is capable of giving out;—in some cases, the volumes of the azotic gas and carbonic acid gas, evolved, were to each other as follows: By charcoal;

1 volume azotic
2½ volumes carbonic acid.

But in general, the gas, unabsorbable by potash, bore a greater ratio to the carbonic acid gas than the preceding; and the longer the heat was continued, the greater was the quantity of unabsorbable gas evolved. There was always evolved, likewise, a very considerable quantity of water. It was impossible to doubt, that the charcoal (though I had previously heated it strongly in a wind furnace) contained both oxygen and hydrogen; and, when I substituted Kilkenny coal for charcoal, my results were not more satisfactory. With Kilkenny coal, the proportion of

water formed was greater, and of carbonic acid smaller, than when charcoal was used.

By iron filings.

My next process was to mix together nitre and clean iron filings—to introduce the mixture into a copper tube—and to expose it to a red heat. In this process, the oxygen of the nitre united with the iron filings, while the azote was evolved in the gaseous state. Four experiments made in this way very nearly agreed with each other. I found, that 8·65 grains of nitre gave out four cubic inches of azotic gas, supposing the barometer to stand at 30 inches, and the thermometer at 60°. It will be more convenient to divide these quantities by 4; this will give, as a result, 1 cubic inch of azotic gas from 2·1625 grains of nitrate of potash.

Now, since the specific gravity of azotic gas is 0·9722, a cubic inch of it weighs 0·296527 grain; and this is the weight of azote in 2·1625 grains of nitre.

But nitre is anhydrous: the atomic weight of nitric acid is 6·75, and of potash 6; consequently, nitrate of potash is composed of

Nitric acid	6·75
Potash	6
	12·75

And 2·1625 grains of nitre contain 1·144852 grain of nitric acid. The preceding experiments

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give us the weight of azote in this quantity of nitric acid, and the remainder of the weight must be oxygen; consequently, nitric acid is composed of

Azote	0·296527	or	1·7477
Oxygen	0·848324	-	5
	1·144852		6·7477

Composition of nitric acid.

But there is obviously a slight inaccuracy in this analysis, for it gives us the atomic weight of nitric acid 6·7477, instead of 6·75, which we found above to be the true quantity. It is clear, that this error lies in the azote, which is a little too low, and not in the oxygen, which must constitute a whole number of atoms. Had I obtained from 8·65 grains of nitre 4·004 cubic inches of azotic gas, instead of 4 cubic inches, this error would not have existed. But my apparatus was not delicate enough to measure the gas evolved so exactly—I may, in reality, have obtained 4·004 cubic inches, without perceiving the slight difference in volume.

There can be no doubt, from these experiments, that the true composition of nitric acid is

Azote	1·75
Oxygen	5
	6·75

Weight of the atom of azote.

Or it is composed of 1 atom of azote and 5

atoms of oxygen; and an atom of azote weighs 1·75.

It appears from an experiment, which I have stated above, that 8·65 grains of saltpetre contain 4·004 cubic inches of azotic gas. Now, as nitre is a compound of 6 potash and 6·75 nitric acid—and as nitric acid is a compound of 1·75 azote and 5 oxygen—it is obvious, that 8·65 grains of nitre contain

Azote	1·187254 gr.	or	4·00386 cubic inches,
Oxygen	3·392155 -	-	10·00960 cubic inches.
	4·579410		

Now, 4·00386 : 10·00960 : : 1 : 2·5. So that the constituents of nitric acid, when converted into gases, consist of

1 volume azotic gas
2½ volumes oxygen gas.

But we have seen already, that half a volume of oxygen gas is equivalent to an atom. It is obvious, that a volume of azotic gas is equivalent to an atom;—in this respect, azotic gas agrees with hydrogen gas, chlorine gas, and the vapour of iodine.

The specific gravity of azotic gas is obtained by multiplying its atomic weight, 1·75, by 0·5555. The product is 0·9722, which we have found to be the true specific gravity of this gas.

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Nitric acid is the compound of azote and oxygen, which contains the maximum quantity of oxygen. It is obtained by heating a mixture of sulphuric acid and nitre, in a retort, to which a receiver is luted. When 6⅛ parts of the strongest sulphuric acid of commerce are mixed with 12½ parts of nitre, thoroughly freed from water, and perfectly pure, the acid which comes over is the strongest that can be procured. Its specific gravity is about 1·55, and it is a compound of 1 atom acid and 1 atom water, or it contains

Method of obtaining nitric acid.

Real acid	85·714 parts
Water	14·286 parts
	100·000

When 12½ parts of sulphuric acid are mixed with 12½ parts of pure anhydrous nitre, the whole nitric acid may be obtained without any loss; but its specific gravity is only 1·4855, and it is a compound of 1 atom real acid, and 2 atoms water.

When nitric acid is quite free from nitrous gas, it is colourless, and nearly as limpid as water; but the presence of this gas gives it a yellow, a red, or a brown colour, according to its quantity. This gas greatly increases the volatility of the acid, but its effect upon the specific gravity is not so great as I had anticipated—the volume of the acid being increased, nearly in proportion to the quantity of gas absorbed.

Cause of its colour.

Table exhibiting its strength.

The following table, from a set of experiments which I made with great care, exhibits the specific gravity of various atomic compounds of real nitric acid and water. The experiments were made, by adding given quantities of water to acid, of the specific gravity 1·4855, and taking the specific gravity of the mixture. The strongest acid which I was able to obtain from nitre, had the specific gravity 1·534. By determining the composition of this acid, and observing the rate at which the specific gravity diminishes with the proportion of water added, I concluded, that acid composed of 1 atom real acid, and 1 atom water, has the specific gravity 1·55.

Atoms of Acid.	Atoms of Water.	Acid in 100.	Specific Gravity.
1	1	85·714	1·55
1	2	75·000	1·4855
1	3	66·668	1·4546
1	4	60·000	1·4237
1	5	54·545	1·3928
1	6	50·000	1·3692
1	7	46·260	1·3456
1	8	42·857	1·3220
1	9	40·000	1·3032
1	10	37·500	1·2844
1	11	35·294	1·2656
1	12	32·574	1·2495
1	13	31·579	1·2334
1	14	30·000	1·2173
1	15	28·571	1·2012

The acid, composed of 1 atom of acid and 4 atoms of water, seems to be the most intimate, for its boiling temperature is the highest, being 248°—while acid, both stronger and weaker than

this, boils at a lower temperature. This is the strength of the acid usually met with in commerce; it contains exactly 60 per cent. of real acid, and 40 per cent. of water. Acid, of the specific gravity 1·3692, contains just half its weight of water;—it boils at the temperature of 248°. Acid of the specific gravity 1·3032, may be considered as just the reciprocal of acid of the specific gravity 1·4237, for it consists of 40 acid + 60 water; whereas, the latter consists of 60 acid + 40 water. Its boiling point is 236°, or 12° lower than that of the acid, whose boiling point is a maximum. These boiling points were determined by Mr. Dalton.

Other compounds of azote and oxygen.

I shall now take a view of the remaining compounds of azote and oxygen;—these are *protoxide of azote*, *deutoxide of azote*, and *nitrous acid*. The knowledge of the atomic weight of azote, and the specific gravity of azotic gas, will enable us to make out the composition of these compounds without difficulty.

Analysis of protoxide of azote.

1. Protoxide of azote, the *nitrous oxide* of Davy, is usually obtained by exposing nitrate of ammonia to a heat of about 400°, or a little higher—it is a colourless gas, having a sweetish taste, and water absorbs about three fourths of its volume of it. If you mix 100 volumes of pure dry protoxide of azote, with 100 volumes of dry hydrogen gas, and pass an electric spark through the mixture, a detonation takes place,

and some water is deposited upon the inside of the eudiometer. If the experiment be made when the barometer stands at 30 inches, and the thermometer at 60°, the residual gas will amount to 101·77 volumes. But this gas is saturated with humidity—if it were quite dry, its volume would be 100.*

Its constitution and atomic weight.

Thus it appears, that when protoxide of azote is mixed with its own volume of hydrogen gas, and fired, the gaseous residue, which is azotic gas, is just equal to the original volume of the gas—the hydrogen gas has disappeared and been converted into water—it must, therefore, have combined with a quantity of oxygen, which, had it been in the state of gas, would have amounted to half the bulk of the hydrogen gas. The constituents of protoxide of azote then are

1 volume of azotic gas
½ volume of oxygen gas } condensed into one volume.

But a volume of azotic, and ½ a volume of oxygen gases, are each equivalent to an atom;—hence this gas is a compound of 1 atom azote + 1 atom oxygen, so that its atomic weight is 2·75.

* Let the volume of dry gas be x, and let $p = 30$; and $f = 0{\cdot}524$. We have

$$\frac{p\,x}{p-f} = 101{\cdot}77$$

The solution of this equation will give $x = 100$.

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Its specific gravity is obviously obtained by adding together the specific gravity of azotic gas, and half the specific gravity of oxygen gas.

Specific gravity of azotic	$= 0{\cdot}972\dot{2}$
$\frac{1}{2}$ specific gravity of oxygen	$= 0{\cdot}555\dot{5}$
	$1{\cdot}527\dot{7}$

I took the specific gravity of this gas three times successively, and obtained each time 1·5269. This is as near an approximation to the truth as I could reach with my balance—and is amply sufficient to satisfy us, that the specific gravity above deduced, from the known specific gravities, volumes, and condensation of its two constituents, is correct.

Analysis of deutoxide of azote.

2. Deutoxide of azote, the *nitrous air* of Priestley, has been long known, and for many years constituted a favourite object of research among chemists. Sir H. Davy was the first person who attempted an accurate analysis of it. From his experiments (*Researches*, p. 122.) it was evident, that it consisted very nearly of equal volumes of oxygen and azotic gases. Gay-Lussac afterwards demonstrated, that its constituents are 1 volume of oxygen, and 1 volume of azotic gases, united together without any condensation. He heated some potassium in 100 volumes of this gas;—after the combustion was at an end, and the whole apparatus cooled down to the

temperature of the apartment, the residual gas, which was pure azote, amounted to exactly 50 volumes,*—the potassium had absorbed the oxygen, which obviously constituted half the volume of the original gas. Now, since ½ a volume of oxygen gas is equivalent to an atom, and 1 volume of azotic gas to an atom, it is evident, that deutoxide of azote is a compound of 2 atoms oxygen, and 1 atom azote; consequently, its atomic weight is 3·75.

Its constitution and weight.

The specific gravity of this gas is the mean between the specific gravity of oxygen and azotic gases, or 1·041$\dot{6}$. For

Sp. gr. of oxygen gas 1·111$\dot{1}$
Sp. gr. of azotic gas 0·972$\dot{2}$

2) 2·083$\dot{3}$

1·041$\dot{6}$ = sp. gr. of deutoxide of azote.

I took the specific gravity of this gas, prepared with as much care, to secure its purity, as possible. The mean of three trials, differing from each other only by unity in the fourth decimal place, was 1·04096. The small difference between this result and the preceding, deduced from theory, which does not exceed $\frac{1}{1488}$th part, is probably to be ascribed to the presence of a little azotic gas, with which it is extremely diffi-

* Mem. d'Arcueil. II. 216.

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cult to prevent it from being contaminated, when the gas is prepared over water.

Berzelius and Dulong, in their paper on the Specific Gravity of Gases, state its specific gravity to be only 1·0010. But this statement cannot be accurate; for it is inconsistent with the specific gravities of oxygen and azotic gases, which they themselves have given. According to them, the specific gravity of

Oxygen gas = 1·1026
Azotic gas = 0·9760

2) 2·0786

1·0393 = sp. gr. of deutoxide of azote, deduced from these data.

These gentleman have rated the specific gravity of deutoxide of azote a great deal too low.

If 1 volume of protoxide of azote, and half a volume of oxygen gas, were to unite and be reduced to $\frac{3}{4}$th of a volume, we should obtain a compound, having the constituents and specific gravity of deutoxide of azote. For

Sp. gr. of protoxide of azote = $1{\cdot}527\dot{7}$
$\frac{1}{2}$ sp. gr. of oxygen gas = $0{\cdot}555\dot{5}$

2) $2{\cdot}083\dot{3}$

$1{\cdot}041\dot{6}$ = sp. gr. of deutoxide of azote.

Analysis of nitrous acid.

3. Nitrous acid is an orange coloured liquid, which may be obtained in a state of purity, by exposing dry nitrate of lead to heat in a retort, while the receiver is surrounded with a mixture of snow and salt. It is a liquid, which, when newly prepared, has an orange colour; but I have never been able to prevent it from acquiring a green colour—a change produced by the absorption of a very small quantity of water. This acid was first obtained in a separate state by Berzelius—Gay-Lussac first ascertained its nature—Dulong analyzed it, by passing it through red hot copper wire. The oxygen united to the copper, while the other constituent, the azote, passed off in the state of gas. By this method of proceeding, he obtained its constituents as follows:—

Azote	1·75
Oxygen	4·178

This is rather more than 4 atoms of oxygen united to 1 atom of azote. But that the true composition of nitrous acid, is 1 atom of azote and 4 atoms of oxygen, is obvious from the following experiment, which I have often repeated.

Introduce into a cylindrical glass tube, 18 inches long and 0·9 inch in its internal diameter, shut at one end, filled with water, and standing inverted over a water trough, 100 volumes of common air;—then let up to this air 100 vol-

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umes of deutoxide of azote ;—the gaseous mixture assumes an orange colour, and diminishes rapidly in volume. When the gas has become again colourless, and has ceased to diminish, its bulk will be found to amount to 138 volumes.

To be able to understand what really takes place in this experiment, we must recollect that common air consists of 20 volumes oxygen gas, and 80 volumes azotic gas ; and that the yellow colour is occasioned by the combination of the oxygen of the common air, with the deutoxide of azote and the formation of nitrous acid. The whole oxygen of the air disappears, and the amount of the residual gas will enable us to judge of the volume of deutoxide, with which it combines.

The experiments were made over water at the temperature of 60°. Had the air and deutoxide been dry, instead of saturated with moisture, each would have occupied only 98·253 volumes instead of 100 ; so that the whole gaseous matter used, had it been dry, would have occupied 196·506 volumes. The 138 volumes of residual gas, supposing them dry, would be reduced to 135·589 volumes. This last quantity subtracted from 196·506 (the original volume) leaves 60·917 volumes for the quantity absorbed or converted into nitrous acid.

Now 98·253 volumes of common air, contain 19·65 volumes of oxygen, which, in order to be

converted into nitrous acid, must have combined with 41·267 volumes of deutoxide of azote. According to this experiment nitrous acid is a compound of

19·65 volumes of oxygen gas
41·267 volumes deutoxide of azote

Or,

20 volumes oxygen gas
42 volumes deutoxide of azote

42 exceeds 20 × 2 only by 2 volumes—and these 2 volumes are absorbed by the air in the water through which it was passed. This air always causes a little of the deutoxide of azote to disappear, and renders its absorption in all experiments made in this way a little greater than the truth.

From the preceding experiment, then, we may conclude that nitrous acid is composed of

1 volume oxygen gas
2 volumes deutoxide of azote.

But we have seen, in a preceding part of this chapter, that deutoxide of azote is composed of 1 volume of azotic and 1 volume of oxygen gas, united, without any condensation. It is obvious, then, that nitrous acid is composed of

1 volume azotic gas
2 volumes oxygen gas.

But a volume of azotic gas being equivalent to an atom, and half a volume of oxygen gas equivalent to an atom, nitrous acid is obviously composed of

1 atom azote
4 atoms oxygen

Its atomic weight.

Hence its atomic weight is 5·75.

Such are the atomic weights and constitutions of all the known compounds of azote and oxygen. Azote appears likewise capable of uniting with chlorine and iodine; the compounds formed possess violently detonating properties, and have not hitherto been applied to any useful purpose. I have not myself made any experiments to determine the composition of these substances. Davy made some experiments on the chloride of azote, from which he deduced its constituents to be

Compounds of azote with chlorine and iodine.

4 atoms chlorine	=	18
1 atom azote	=	1·75
		19·75

Gay-Lussac, from theoretical considerations, considers the iodide of azote to be a compound of

3 atoms iodine	=	36·5
1 atom azote	=	1·75
		37·25

It would be very difficult to analyze it, for it de-

tonates on the slightest motion; often, indeed, spontaneously without any agitation whatever.

But azote enters into a combination with hydrogen, of considerable interest in a chemical point of view, as it constitutes ammonia, or volatile alkali, so much employed in chemical analyses, and so often formed during the decomposition and putrefaction of animal substances.

Ammonia

Ammonia, in a state of purity, is a gaseous substance, easily obtained by heating a mixture of sal-ammoniac and quicklime. $3\frac{1}{2}$ parts of pure quicklime are sufficient to decompose $6\frac{3}{4}$ parts of sal-ammoniac; but it is better to add a considerable excess of quicklime. Indeed, I always fill the small retort in which the sal-ammoniac is put with quicklime, which is of service by preventing the two speedy extrication of moisture, which stops the evolution of the gas.

Ammoniacal gas must be received over mercury; for it is the most absorbable of all the gases by water, 1 volume of that liquid absorbing 780 volumes of ammoniacal gas.

Analysis of

When pure dry ammoniacal gas in a glass tube, standing over mercury, is exposed to a continued series of electrical sparks passed through it, decomposition takes place; its volume is just doubled; and it is found to consist of a mixture of one volume azotic and three volumes hydrogen gas. This experiment was first made by M. Berthollet senior. It was afterwards re-

peated with great care by M. Berthollet junior, Sir H. Davy, and Dr. Henry.* What I have just stated, is the obvious deduction from these elaborate and difficult experiments. As in azotic and hydrogen gases, volumes are equivalent to atoms, it follows that ammonia is a compound of

1 atom azote	=	1·75
3 atoms hydrogen	=	0·375
		2·125

So that its atomic weight is 2·125. Its atomic weight.

Ammoniacal gas has been shown to be a compound of one volume azotic and three volumes hydrogen gas, condensed into two volumes. Its specific gravity, of course, will be obtained by adding together the specific gravity of azotic gas, and three times the specific gravity of hydrogen gas, and dividing the sum by two. This gives us 0·59027 for the true specific gravity of this gas.

Sir H. Davy took the specific gravity of this gas with great care, and obtained for a result

* Dr. Henry, in a paper on the Analysis of the Aeriform Compounds of Nitrogen, printed in 1824, but not yet published, has repeated the analysis of ammonia with still greater care, and has obtained results which scarcely differ from those in the text. The ammoniacal gas was doubled by the electric sparks, and the gas, thus increased in volume, was found a mixture of one volume azotic and three volumes hydrogen gas.

Dr. Henry's analyses of protoxide of azote, deutoxide of azote, and nitric acid, fully confirm the statements in the preceding part of this chapter.

0·590164. A set of experiments to determine the specific gravity of this gas, made with great care in my laboratory, gave (the mean of three trials) 0·59031. Davy found the specific gravity of this gas a little below the theoretical result, while I obtained it a little above it—but if we take the mean between these two specific gravities, we obtain 0·590237, which differs from the theoretical result by less than $\frac{1}{10000}$th part. There cannot be the least doubt that the atomic weight and specific gravity of ammoniacal gas have been determined with precision.

But as the exact knowledge of the composition of this substance is a most important point in the theory of chemistry, it will not be amiss to exhibit even a redundancy of evidence. I shall, therefore, add a few additional experiments.

Analysis of oxalate of ammonia.

1. Oxalate of ammonia is a neutral salt, which crystallizes in beautiful transparent prisms. It is not very soluble in water. Its constituents I have found, by a careful analysis, to be

1 atom oxalic acid	.	4·5
1 atom ammonia	.	2·125
2 atoms water	.	2·25
		8·875

8·875 grains of this salt were dissolved in a small quantity of distilled water. 6·25 grains of pure calcareous spar (equivalent to 3·5 grains of lime)

were dissolved in muriatic acid: the solution was evaporated to dryness, and the dry residual salt, constituting muriate of lime, was re-dissolved in a little water. The two solutions being mixed, a double decomposition took place, and oxalate of lime subsided to the bottom. As soon as the supernatant liquid had become quite clear, it was tested by oxalate of ammonia, and by muriate of lime; but was not rendered muddy by either of these reagents,—showing that it contained no lime nor oxalic acid. From this it is obvious, that 8·875 grains of oxalate of ammonia contain just the quantity of oxalic acid requisite to saturate 3·5 grains of lime. Now, 3·5 being the atomic weight of lime, the oxalic acid in 8·875 grains of the oxalate must be the equivalent of an atom, or 4·5; for it will be shown afterwards that 4·5 is the atomic weight of oxalic acid.

The liquid from which the oxalate of lime had precipitated was neutral: hence the muriatic acid in the muriate of lime was just capable of saturating the whole ammonia in the 8·875 grains of oxalate of ammonia. Now, this muriatic acid weighed exactly 4·625 grains. And it will be shown in the next paragraph, that 4·625 grains of muriatic acid just saturate 2·125 grains of ammonia. This, therefore, is the quantity of ammonia in 8·875 grains of oxalate of ammonia.

We have thus determined the weight of acid and ammonia in 8·875 grains of oxalate of ammonia. The surplus weight being undoubtedly water, it is obvious that the constituents of oxalate of ammonia are

1 atom oxalic acid	.	4·5
1 atom ammonia	.	2·125
2 atoms water	.	2·25
		8·875

The atomic weight of ammonia in this salt is undoubtedly 2·125.

Of sal-ammoniac.

2. Sal-ammoniac, when newly sublimed, or when dried for some time upon the sand bath, is an anhydrous salt. It is neutral; and, therefore, a compound of one atom muriatic and one atom ammonia.

1 atom muriatic acid	.	4·625
1 atom ammonia	.	2·125
		6·75

6·75 grains of pure dry sal-ammoniac were dissolved in water; 21·5 grains of pure anhydrous nitrate of silver were dissolved in another portion of water, and the two solutions were mixed. A double decomposition took place, and chloride of silver precipitated. As soon as the residual liquid had become clear, it was tested by nitrate of silver and common salt. Neither of these

salts produced any effect, if we except an almost imperceptible opalescence which appeared when the common salt was added; but there was no precipitate whatever, even after the liquid had stood a week. From this experiment it is obvious, that 6·75 grains of sal-ammoniac contain just 4·625 grains of muriatic acid; for that is the quantity necessary to saturate the 14·75 grains of oxide of silver present in 21·5 grains of nitrate of silver. Hence the other constituent of the salt, the ammonia, must weigh 2·125, because that is the weight wanting to make up the full quantity of sal-ammoniac employed; and, as sal-ammoniac is neutral, and 4·625 the atomic weight of muriatic acid, 2·125 must be the atomic weight of ammonia.

Analysis of ammonia by chlorine.

3. 13·5 grains of dry sal-ammoniac were wrapped up in blotting paper, and dropped into a retort filled with dichloride of lime, (Mr. Tennant's bleaching powder,) made into a thin paste with water. The whole retort and beak was then filled with water, and the beak of the retort was plunged into a water trough, under an inverted graduated jar, filled with water. As soon as the paper round the sal-ammoniac was sufficiently softened to allow the dichloride to come in contact with the salt, an effervescence took place, and azotic gas was disengaged. This is just the effect always produced when chlorine and ammoniacal gas come in contact. The lime which

was in excess in the salt decomposed the sal-ammoniac; and the ammonia, as it was evolved, came in contact with chlorine, and was decomposed; the hydrogen uniting with the chlorine, and the azote being disengaged in the gaseous state. The action is so violent, if the dry sal-ammoniac be dropped at once into the retort, that it is difficult to collect the whole gas; but when the salt is wrapped in paper, the action is slow, and the gas may be all collected with the greatest facility. The azotic gas obtained in this process was 11·7 cubic inches, at the temperature of 47°, and when the barometer stood at 29·93 inches. This is equivalent to 11·853 cubic inches of dry gas, of the temperature 60°, and under a pressure of 30 inches mercury.

This constitutes the whole amount of the azotic gas in 4·25 grains of ammonia, the quantity contained in 13·5 grains of dry sal-ammoniac. Now, 11·853 cubic inches of azotic gas weigh 3·5147 grains: Hence it follows, that the weight of the other constituent, the hydrogen, is 0·7353 grain. Consequently, ammonia is composed of

Azote	1·7573	or	1 volume
Hydrogen	0·3676	—	2·94
	2·1250		

The small excess of azote in this experiment was owing to a small admixture of common air with

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the azote, in consequence of the gas standing 24 hours over the water.

The experiment was repeated seven times, in various ways, and the mean of the whole came exceedingly near 11·8 cubic inches of dry azotic gas from 13·5 grains of sal-ammoniac. This weighs 3·4993 grains, giving us the composition of ammonia as follows;

Azote	1·74965	or	1 volume
Hydrogen	0·37535	—	3·0028
	2·12500		

This analytical result of direct experiment comes within less than $\frac{1}{1000}$th part of the theoretical estimate; and, taken together with the preceding facts, can leave no doubt of the composition of ammonia.

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CHAP. VI.

OF THE ATOMIC WEIGHTS OF THE ACIDIFIABLE COMBUSTIBLES.

The simple bodies, which I have distinguished by the name of acidifiable combustibles, are the nine following:

1 Hydrogen,	4 Silicon,	7 Selenium,
2 Carbon,	5 Phosphorus,	8 Arsenic,
3 Boron,	6 Sulphur,	9 Tellurium.

I have already treated of hydrogen in the first chapter of this work. I shall endeavour in this chapter to establish the atomic weights, and to point out the principal combinations of the remaining eight. These bodies differ from all the other combustible substances in the property which they have of entering into gaseous compounds, either with hydrogen gas or fluoric acid, while none of the other combustible bodies enter into any gaseous combination whatever. An accurate knowledge of their atomic weights will be found important, not merely as connected with chemical analysis; but because it throws an important light on the relation between the atomic weight and the specific gravity of gaseous bodies.

SECT. I.

OF THE ATOMIC WEIGHT OF CARBON.

British chemists seem all agreed in opinion respecting the atomic weight of carbon. It is to the atom of oxygen as 6 to 8; consequently, if an atom of oxygen be reckoned unity, an atom of carbon must be represented by 0·75. Berzelius, who is followed by a great proportion of the chemists on the continent, considers the atomic weight of carbon to be 0·7533. As this number differs nearly 1 per cent. from 0·75, I have been at great pains to endeavour to determine which of the two is nearest the truth; and I shall here describe a set of experiments which I made, with that specific object in view, with every possible attention to the most minute accuracy.

Carbonic acid gas contains its volumes of oxygen gas.

It was established by the experiments of Lavoisier, and has been amply confirmed by succeeding experimenters, that when carbon is burnt in oxygen gas, the volume of the gas undergoes no alteration; but it is converted into carbonic acid. It is obvious from this that, if we subtract the specific gravity of oxygen gas from that of carbonic acid gas, the remainder will give us the weight of carbon with which a volume of oxygen gas has united; and, of course,

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furnish us with the requisite data for determining the exact composition of carbonic acid gas.

We have three sets of experiments on the specific gravity of carbonic acid gas, which appear to have been made with great care. The following are the results obtained:

SP. GR. OF CARBONIC ACID GAS.		
1·5196	.	by Biot and Arago.
1·52673	.	by my experiments.
1·5240	.	by Berzelius and Dulong.

These results differ too much from each other to enable us to deduce from them the composition of carbonic acid, with the requisite degree of precision; nor have we any criterion by which we can discover which of the three results is nearest the truth. My own determination is the highest, and that of Biot and Arago the lowest. Now, if any error resulted from the impurity of the gas weighed, the probability is, that it would diminish the specific gravity somewhat; for, common air, the only gas likely to contaminate the carbonic acid gas examined, is a good deal lighter. So far the probability of accuracy rather inclines to my own result; but it is not sufficient to enable us to decide the point, far less to determine whether my own result be not in reality a little too low. This uncertainty suggested to me a method similar to that by which the specific gravities of oxygen and hydrogen gases

were determined in the first chapter of this work. I shall now lay the result of these experiments before the reader.

Composition of carbonate of lime.

1. It is well known, that, when calcareous spar or carbonate of lime is exposed to a white heat, it loses its carbonic acid, and is converted into quicklime. I exposed given quantities of very pure crystallized calcareous spar, inclosed in a platinum crucible, covered with a lid, to the greatest heat of a wind furnace, in order to determine the weight of carbonic acid which would be driven off. The loss of weight in different trials was not rigidly the same. However, by a number of experiments, varied by uniting the lime to sulphuric acid, and determining the weight of sulphate of lime remaining after ignition, I satisfied myself, that, when none of the lime is lost, and when the carbonate is anhydrous, 100 grains of it, when deprived of its carbonic acid, lose exactly 44 grains. The remaining 56 grains are lime. Carbonate of lime, then, is a compound of

Carbonic acid	44	or	11
Lime	56	—	14
	100		25

It will appear afterwards, that the atomic weight of lime is 3·5. Now, 14 : 11 : : 3·5 : 2·75; so that (if carbonate of lime be a com-

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pound of 1 atom lime and 1 atom carbonic acid) the atomic weight of carbonic acid is 2·75. The following experiment, which I have repeated more than once, will show that this determination is rigidly exact.

Atomic weight of carbonic acid determined.

2. I must begin by stating, what will be afterwards proved, that an atom of potash weighs 6. This alkali combines in two proportions with carbonic acid, forming a *carbonate*, composed of 1 atom potash, united to 1 atom carbonic acid; and a *bicarbonate*, composed of 1 atom potash, and 2 atoms carbonic acid. The latter of these salts crystallizes in large transparent and permanent crystals, not affected by exposure to the air. It can easily be procured in this state in this country, very nearly pure, being only occasionally contaminated by a little lime and a little iron. If we dissolve these crystals in distilled water, filter the solution, evaporate it to dryness, and expose the saline residue to a red heat, we obtain anhydrous carbonate of potash in a state of great purity. Dissolve 87½ grains of this salt in water; dissolve in muriatic acid 62½ grains of pure anhydrous carbonate of lime; evaporate the solution to dryness, in a gentle heat, to drive off the excess of acid; and dissolve the muriate of lime formed in distilled water. Thus we have two solutions, containing each determinate quantities of a particular salt: the first solution, 87½ grains of carbonate of potash, and the

second, a quantity of muriate of lime equivalent to 62½ grains of carbonate. When these two solutions are mixed, a double decomposition takes place; the lime and carbonic acid unite together, and precipitate in the state of carbonate of lime, while the muriatic acid and potash remain in solution, constituting muriate of potash. If we examine the clear residual liquid after the carbonate of lime has precipitated, we shall find in it no uncombined potash, and no carbonate of potash; for, cudbear paper, dipped into it, is not in the least altered,—although a very minute quantity of uncombined alkali, or alkaline carbonate, gives it a violet stain. Neither does it contain any sensible quantity of lime; for it is not in the least altered by the addition of a few drops of oxalate of ammonia. When the precipitated carbonate of lime is collected and dried, it weighs exactly 62½ grains, or is just equal to the original quantity of carbonate of lime employed—a clear proof that it contains all the lime and all the carbonic acid of the two salts.

This experiment will be more easily understood if we divide the quantities employed by 10. We thus get 8·75 grains of carbonate of potash, and 6·25 grains of carbonate of lime—each constituting an integrant particle of the anhydrous salt; for carbonate of potash is composed of

Carbonic acid	2·75
Potash	6
	8·75

And carbonate of lime of

Carbonic acid	2·75
Lime	3·5
	6·25

The carbonic acid was separated from this carbonate, and an atom of muriatic acid, weighing 4·625, was substituted in its place—forming muriate of lime, composed of

Muriatic acid	4·625
Lime	3·5
	8·125

The 3·5 lime and the 2·75 carbonic acid united together, and formed 6·25 carbonate of lime. In the same way, the 6 potash and the 4·625 muriatic acid united together; and these respective quantities of acid and base exactly neutralized each other: for both the carbonate of lime and the muriate of potash were perfectly neutral. It is clear from this experiment, that the atomic weight of carbonic acid is just 2·75.

3. Two facts of great importance have been ascertained by the preceding experiments; namely, 1. That an atom of carbonic acid weighs 2·75. 2. That 100 grains of pure carbonate of lime contain exactly 44 grains of carbonic acid.

Specific gravity of carbonic acid gas determined.

The next object which engaged my attention was, to disengage the carbonic acid from 100 grains of calcareous spar, and collect it over mercury, in order to ascertain its volume. This experiment appears so easy, that the reader will be surprised to hear, that a considerable time elapsed, and many fruitless experiments were made, before I was able to make it with accuracy.

The first method that I tried was, to fill a graduated glass jar with mercury, to let up into it some muriatic acid, and then to introduce a given weight of calcareous spar. By this method the carbonic acid was extricated with great rapidity; but the volume of gas obtained was always considerably greater than it ought to have been, judging from my previous knowledge of the specific gravity of carbonic acid gas. The reason I found to be, that a portion of the muriatic acid had been disengaged in the form of gas, had mixed with the carbonic acid gas, and had augmented its volume. Thus the gas from 100 grains of calcareous spar sometimes amounted to 109½ cubic inches; while I knew that the true volume of the gas, if pure, could not exceed 94½ cubic inches.

I attempted to prevent this extrication of muriatic acid gas, by employing very weak muriatic acid for dissolving the calcareous spar; but when the experiment was made in this way, the volume of carbonic acid gas extricated fell al-

ways a little below the truth. The reason I found to be, that a portion of the carbonic acid remained in the liquid muriatic acid, and did not assume the gaseous form at all.

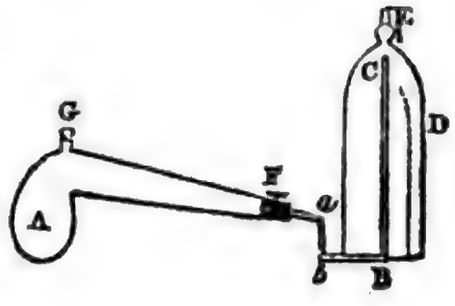
When acetic acid was used, the extrication of gas went on very slowly, unless the carbonate of lime was in powder; and the gas extricated was always below the true quantity, because it did not all assume the elastic state.

Sulphuric acid did not answer well, because the sulphate of lime formed was apt to screen some of the calcareous spar from the action of the acid, and thus to prevent the whole gas from being obtained.

Oxalic, tartaric, and citric acids, could not be used, for a similar reason. Nitric acid was excluded, because it acted on the mercury.

Foiled in my attempts to determine the volume of carbonic acid gas extricated from a given weight of calcareous spar by the above method, I had recourse to another, which succeeded perfectly.

To the beak of a small retort, A, I cemented a long glass tube, bent at right angles, at *a*, *b*, and B, and the upright leg, B, C, of such a length, that it reached very nearly to the top of the graduated glass



jar D, fitted at its top E with a stop cock. The capacity of the retort was 36 cubic inches. This apparatus was attached to a mercurial trough, so that the jar D could be placed over the upright tube B, C. The stop-cock F being shut, I opened the stop-cock E, and with my mouth sucked the air out of the jar till only 5 cubic inches remained in it, over a column of 8 inches of mercury; the stop-cock E was then shut. I next took out the stopper G, the stop-cock F remaining shut, and poured into the retort a cubic inch of strong nitric acid. 100 grains of calcareous spar, in three or four pieces were then dropped into the retort, and the stopper being at the same instant put into its place, the stop-cock F was opened. The whole calcareous spar was speedily dissolved, and the carbonic acid gas made its way into the cylinder D. When the experiment was over, I noted the volume of gas in the cylinder, the height of the column of mercury below it (generally about 1 inch), and the height of the barometer and thermometer at the time. Knowing exactly the volume of air in the apparatus before the experiment began, it was easy, by subtracting it from the total quantity of air in the apparatus after the experiment, to deduce the volume of carbonic acid gas evolved. All the necessary reductions being made, the volume of carbonic acid gas evolved from 100 grains of calcareous

spar, supposing the barometer to stand at 30 inches, the thermometer at 60°, and the gas to be perfectly dry, amounts, from a mean of two experiments, both made with very great care, to 91·426 cubic inches.

Now, we have seen that the weight of this volume of carbonic acid gas is 44 grains. Consequently, 100 cubic inches of carbonic acid gas must weigh 46·5973 grains; but 100 cubic inches of air weigh 30·5 grains. We have, therefore, 30·5 : 46·5973 : : 1 : 1·52778 = specific gravity of carbonic acid gas.

Thus the specific gravity of carbonic acid gas, determined by ascertaining the volume of a given weight, amounts to 1·52778. By means of a nonius and a microscopic sight, I was enabled to measure the volume of gas with precision to the thousandth part of a cubic inch. My result, therefore, must be very near the truth. It is not, however, quite exact. But, by means of a law, which I shall explain more at length in the following chapter, we have it in our power to determine the specific gravity of this gas with mathematical accuracy; for, its atomic weight, multiplied by 0·5555̇, (half the specific gravity of oxygen gas,) is equal to its specific gravity. Now, we have seen that the atomic weight of this acid is 2·75; and 2·75 × 0·5555̇ = 1·5277̇, which is the true specific gravity of this gas. My estimate, deduced in the way just explained,

does not exceed this quantity by so much as $\frac{1}{700.000}$th part.

Composition of carbonic acid.

The specific gravity of carbonic acid gas being thus ascertained with rigid accuracy, we have only to subtract from it the specific gravity of oxygen gas, to know the weight of carbon united in it, with a volume of oxygen gas.

Sp. gr. of carbonic acid gas	1·5277̇
oxygen gas	1·1111̇
	0·4166̇ = carbon

Thus we learn, that this acid is composed of

Oxygen	1·1111̇	or 2
Carbon	0·4166̇	or 0·75

Atomic weight of carbon.

2 denotes 2 atoms of oxygen; and 0·75 must be the atomic weight of carbon. Thus it appears, that carbonic acid is a compound of 2 atoms of oxygen, and 1 atom of carbon.*

The carbon in this gas is evidently in the state of vapour. If we consider the gas as a com-

* If the specific gravities of oxygen gas and carbonic acid gas were 1·1026 and 1·5240, as stated by Berzelius and Dulong, an atom of carbon would be 0·76438, a number considerably higher than the one pitched upon by Berzelius; for, 1·5240 — 1·1026 = 0·4214 = the quantity of carbon in a volume of carbonic acid; so that carbonic acid would be a compound of

Oxygen	1·1026	or 2
Carbon	0·4214	or 0·76438

It is obvious from this, that these specific gravities cannot be accurate.

pound of 1 volume oxygen gas and 1 volume carbon vapour, condensed into one volume, it is obvious that the specific gravity of carbon vapour is 0·4166. As is the case with hydrogen, azotic, and chlorine gases, a volume of it is equivalent to an atom.

Composition of carbonic oxide ascertained.

II. Carbon enters into another gaseous combination with oxygen, namely, the gas distinguished by the name of *carbonic oxide*. The atomic weight of this gas is not of so much importance as that of carbonic acid, because we do not know any compounds of which it constitutes a part; but it will be worth while to determine it, because the knowledge of it will serve still farther to elucidate and confirm the preceding conclusions respecting the atomic weight of carbon.

Carbonic oxide was discovered by Dr. Priestley, but its nature was first ascertained by Mr. Cruikshanks. M. M. Clement and Desormes made a set of experiments on it nearly at the same time, or very soon after Cruikshanks, and came to the same conclusion with him: namely, that it is a compound of oxygen and carbon without any hydrogen.

I have never succeeded in obtaining it absolutely free from all admixture of carburetted hydrogen gas. Its specific gravity according to my trials is 0·9700. But, owing to the carburetted hydrogen which it contained, this result is too

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low. Berzelius and Dulong state its specific gravity to be 0·9727. This is rather too high; but it is a good deal nearer the truth than mine.

When 100 volumes of this gas are mixed with 50 volumes of oxygen gas, and an electric spark passed through the mixture, combustion takes place, both gases disappear, and a quantity of carbonic acid gas is formed just equal to the original volume of the carbonic oxide gas employed. This fact, which has been sufficiently established by experiment, will enable us to determine the true specific gravity of this gas, and likewise its constituents and its atomic weight.

1. Since half a volume of oxygen gas added to one volume of carbonic oxide gas constitutes one volume of carbonic acid gas, it is obvious that, if from the specific gravity of carbonic acid gas, we subtract half the specific gravity of oxygen gas, the remainder will be the specific gravity of carbonic oxide gas.

Sp. gr. of carbonic acid gas	=	$1{\cdot}527\dot{7}$
$\frac{1}{2}$ sp. gr. of oxygen gas	=	$0{\cdot}555\dot{5}$
		$0{\cdot}972\dot{2}$ = sp. gr. of carbonic oxide gas.

Thus we learn, that the specific gravity of this gas is $0{\cdot}972\dot{2}$, or exactly the same with that of azotic gas. The specific gravity of it as given by Berzelius and Dulong, exceeds the truth by little more than $\frac{1}{2000}$ part.

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2. It was observed in a former part of this chapter, that carbonic acid gas contains just its own volume of oxygen gas. But to convert a volume of carbonic oxide gas into a volume of carbonic acid gas, we must add half a volume of oxygen gas. It is evident from this, that a volume of carbonic oxide gas contains just the volume of carbon that carbonic acid gas does, but only half the volume of oxygen gas. It must therefore consist of one volume carbon vapour, and half a volume oxygen gas condensed into one volume.

1 volume carbon vapour weighs	$0{\cdot}4166\dot{6}$
$\frac{1}{2}$ volume oxygen gas. . .	$0{\cdot}5555\dot{5}$
	$0{\cdot}9722\dot{2}$ = specific gravity of carbonic oxide gas.

3. A volume of carbon vapour being equivalent to an atom, and half a volume of oxygen gas to an atom, it is obvious that carbonic oxide is a compound of one atom carbon, and one atom oxygen. Hence its atomic weight is 1·75.

Thus we have two compounds of carbon and oxygen.

	CARBON.		OXYGEN.
Carbonic oxide composed of	1 atom	+	1 atom
Carbonic acid . . .	1	+	2

The last of these only possesses acid properties. The first has no tendency whatever to unite with alkaline bases.

III. There are several gaseous combinations of carbon and hydrogen, which were long confounded under the general appellation of heavy inflammable airs. Their nature and constitution deserve to be pointed out, because they constitute the gaseous substances employed for giving light during the night; and they differ materially from each other in their illuminating powers. They may be divided into two species, which have been distinguished by the names of *olefiant gas*, and *carburetted hydrogen gas*.

Analysis of olefiant gas.

1. Olefiant gas was first examined by the Dutch chemists; but we are indebted to Mr. Dalton for an accurate knowledge of its composition. Its specific gravity, as determined by my experiments, is 0·9709; but Berzelius and Dulong found it as high as 0·9804. It will be seen immediately, that my result is about $\frac{1}{74}$th part too low; while that of Berzelius and Dulong is about $\frac{1}{113}$th part too high.

It was shown long ago by Mr. Dalton, and the observation was confirmed by my experiments, that one volume of olefiant gas requires for complete combustion, three volumes of oxygen gas, and the gas remaining after the combustion amounts to two volumes of carbonic acid gas. The knowledge of this fact will enable us to determine the specific gravity, the composition, and the atomic weight of this gas with rigid accuracy.

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(1.) Three volumes of oxygen gas being necessary to consume one volume of olefiant gas, and only two volumes of carbonic acid gas being formed, it is obvious that only two volumes of the oxygen gas were employed in forming carbonic acid; the other volume of oxygen gas must have been employed in forming water, and it must have combined with a quantity of hydrogen, which, had it been in the gaseous state, and uncombined, would have amounted to just two volumes. The two volumes of carbonic acid gas contain each a volume of carbon vapour.

Thus it appears, that one volume of olefiant gas is composed of two volumes of carbon vapour, and two volumes of hydrogen gas condensed into one volume. Its specific gravity, therefore, will be obtained by adding together twice the specific gravity of carbon vapour, and twice the specific gravity of hydrogen gas.

Twice the sp. gr. of carbon vapour	=	0·8333
Twice the sp. gr. of hydrogen gas	=	0·1388
		0·9722 = specific gravity of olefiant gas.

Thus it appears that azotic gas, carbonic oxide gas, and olefiant gas have the same specific gravity.

(2.) In the case of carbon vapour and hydrogen gas, a volume is equivalent to an atom;—so that olefiant gas is a compound of two atoms

carbon and two atoms hydrogen. This is the same thing as one atom carbon and one atom hydrogen. Consequently, this gaseous compound ought to be distinguished by the name of *carburetted hydrogen*, had not that name, unfortunately, been previously appropriated to a different gas.

Five gases exist composed of equal atoms of carbon and hydrogen.

But this combination of carbon and hydrogen, atom to atom, in the gaseous state, deserves to fix our particular attention. I believe that no fewer than five different gases or vapours exist, composed of these two substances in that proportion, but coupled together in different ways.

First species.

The first consists of

1 volume carbon vapour
1 volume hydrogen gas. } condensed into 1 volume.

Its specific gravity is 0·4861. One volume of it requires for complete combustion, $1\frac{1}{2}$ volume of oxygen gas. After the combustion there remains one volume of carbonic acid gas.

This peculiar gas has not yet been met with by chemists; but I see no reason to doubt its existence. It probably exists occasionally as a constituent of coal gas.

Second species.

The second is *olefiant gas*, composed of

2 volumes carbon vapour
2 volumes hydrogen gas } condensed into 1 volume.

Its specific gravity is 0·9722. One volume of it requires for complete combustion three vo-

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lumes of oxygen gas. After combustion there remain two volumes of carbonic acid gas.

This gas is formed when alcohol and sulphuric acid, in the proportion of one part of the former to four of the latter, are heated. It exists also as a constituent of coal gas.

The third consists of — Third species.

3 volumes carbon vapour
3 volumes hydrogen gas } condensed into 1 volume.

Its specific gravity is 1·4583. It requires 4½ times its volume of oxygen gas for complete combustion; and the residual gas consists of three volumes of carbonic acid gas.

Mr. Dalton discovered this gas as a constituent in the gas extricated, when whale oil is exposed to a red heat. This gas is employed for lighting houses, and even streets, under the name of *oil* gas.

The fourth consists of — Fourth species.

4 volumes carbon vapour
4 volumes hydrogen gas } condensed into 1 volume.

Its specific gravity is 1·9444. It requires six times its volume of oxygen gas for complete combustion; and a volume of it, thus burnt, leaves four volumes of carbonic acid gas as a residue.

The vapour of sulphuric ether constitutes a gaseous body of this kind. But in this vapour there exists, likewise, a volume of the vapour

of water. Hence, the specific gravity of ether vapour is 2·5694̇; for it consists of

1 volume of quadro-carburetted hydrogen	1·9444̇
1 volume of vapour of water . .	0·6250
	2·5694̇ = sp. gr. of ether vapour.

Fifth species.

The fifth consists of

6 volumes carbon vapour
6 volumes hydrogen gas } condensed into 1 volume.

Its specific gravity is 2·916̇6. It requires nine times its volume of oxygen gas to consume it completely: and when 1 volume of it is consumed in this way, there remain behind 6 volumes of carbonic acid gas as a residue.

I find, that the vapour of naphtha, from coal, constitutes a gaseous compound of this kind. It is not condensed by passing it through water; and is, I believe, what gives coal gas its peculiar smell.

These gaseous bodies are chiefly used for lighting the streets and illuminating houses. Now, it is obvious, that the quantity of light which they will emit while burning, will be proportional to the number of volumes of carbon condensed into 1 volume of the gas. Olefiant gas burns with great brilliancy; but the vapour of naphtha will give three times as much light,

while the same volume of it is burning. This vapour, then, if we could get rid of the smell, would be the best substance for giving light;—one obvious method would be, to take care that the whole of it is consumed, and that none escapes under the form of naphtha vapour.

Carburetted hydrogen analyzed.

2. Carburetted hydrogen gas can only be obtained pure, by stirring the mud at the bottom of stagnant waters, during hot weather. It was first accurately examined by Mr. Dalton. Soon afterwards, I published a set of experiments on it, in the first volume of the Wernerian Memoirs. I took its specific gravity at two different times, with great care. Gas, collected at Restalrig, near Edinburgh, had the specific gravity of 0·5554. The mean of the specific gravity of three specimens, collected in the neighbourhood of Glasgow, was 0·5576. It will be proper to state each of these trials, as the gas was collected at three different times.

1st trial	0·5602
2d trial	0·5558
3d trial	0·5570

It is obvious that the gas was not of equal purity in each of these trials;—it was purest in the second specimen, the specific gravity of which comes nearest that of my former experiments. The mean of the two gives us 0·5556, which is undoubtedly very near the truth. Berzelius and Dulong state the specific gravity of this gas to

be 0·5590:—this nearly agrees with the specific gravity of the first specimen of gas collected by me near Glasgow.

It has been established by accurate experiments, that a volume of this gas requires, for complete combustion, two volumes of oxygen gas, and that the residual gas is one volume of carbonic acid. From this fact, it is easy to deduce the true specific gravity, the composition, and the atomic weight of this gas.

(1.) One volume of the oxygen gas must have gone to the formation of carbonic acid gas, and must have united with 1 volume of carbon vapour;—the other volume of oxygen gas must have gone to the formation of water, and must have united with two volumes of hydrogen gas. Thus it appears, that the constituents of carburetted hydrogen gas, are one volume carbon vapour, and 2 volumes hydrogen gas, condensed into 1 volume. Hence, its specific gravity will be obtained by adding together the specific gravity of carbon vapour, and twice the specific gravity of hydrogen gas.

Sp. gr. of carbon vapour	$= 0{\cdot}4166\dot{6}$
2 sp. gr. of hydrogen gas	$= 0{\cdot}1388\dot{8}$
	$0{\cdot}5555\dot{5}$ = sp. gr. of carburetted hydrogen gas.

Or its specific gravity is exactly half that of oxygen gas.

(2.) In the case of carbon vapour and hydrogen gas, we may substitute atoms for volumes. It is obvious, therefore, that this gas is a compound of 1 atom carbon, and 2 atoms hydrogen. And as an atom carbon weighs 0·75, and an atom of hydrogen 0·125, the atomic weight of this substance is unity, or the same as oxygen. Its specific gravity is only half that of oxygen gas; because, a volume of oxygen gas is equivalent to two atoms, while a volume of this gas is equivalent only to one atom.

Naphthaline, or sesquicarburetted hydrogen.

3. There exists a third combination of carbon and hydrogen, which has come to our knowledge since coal gas was employed for lighting the streets. It was first noticed by Mr. Garden, who described some of its most remarkable properties, in the year 1820.* Soon after, I got from Mr. Cooper a considerable quantity of this substance, which I purified by sublimation, and subjected to a chemical examination. A valuable set of experiments on this substance was made by Dr. Kid, and published in the Philosophical Transactions for 1821;—he gave it the name of *Naphthaline*. I have only to refer the reader to this interesting paper for a satisfactory explanation of the formation and properties of this singular substance. But, as Dr. Kid made no experiments to determine its constituents, it may

* Annals of Philosophy, XV. 17.

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be worth while to state here the results which I obtained. One grain and a quarter of naphthaline, in crystalline plates, was mixed with a sufficient quantity of oxide of copper, and exposed to heat in a copper tube—to which was attached a glass tube, filled with fragments of fused muriate of lime. The gas extricated was collected over mercury; it was pure carbonic acid; and measured under the mean temperature and pressure 8·85 cubic inches. The increase of weight of the muriate of lime was very nearly 1·125 grain. Now, 8·85 cubic inches of carbonic acid gas weigh very nearly 4·125 grains, and contain 1·125 of carbon; and 1·125 water contain 0·125 hydrogen. Now, 1·125 carbon = 1½ atom; while 0·125 hydrogen is an atom of hydrogen. Consequently, naphthaline is composed of

1½ atom carbon	1·125
1 atom hydrogen	0·125
	1·25

It is, therefore, a sesquicarburet of hydrogen.

Dr. Kid states, that the specific gravity of naphthaline is a little heavier than that of water. I found its specific gravity only 0·7812 at 60°. But I am disposed to ascribe this apparent lightness to the pores which it contains;—for when digested in nitric acid, its specific gravity became 1·23. But this digestion alters its properties, and

converts it into a kind of acid, which has a yellow colour, and very different properties from the pure naphthaline.

SECT. II.

OF THE ATOMIC WEIGHT OF BORON

THE experiments of Davy, and of Gay-Lussac and Thenard, to determine the composition of boracic acid by the augmentation of weight which takes place when boron is converted into boracic acid, differ so much from each other, that it is impossible to put any confidence in either. Davy found that 30 grains of potassium were requisite to reduce a quantity of boracic acid capable of furnishing 2·375 grains of boron. Now, 30 grains of potassium when converted into potash, (as they were by the process) absorb 6 grains of oxygen. Hence, we have boracic acid composed of

Atom of boracic acid still doubtful.

Boron	2·375	or 1
Oxygen	6	- 2·52

He found farther, that 1 grain of boron, when converted into boracic acid, absorbs 5·125 cubic inches of oxygen gas, or 1·7368 grain. This gives us boracic acid composed of

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Boron	1
Oxygen	1·7368

The mean of these two experiments gives us the composition of boracic acid as follows:

Boron	1
Oxygen	2·128

Now, I am persuaded that this comes nearer the truth than any other analytical results which have been given to the public.

The statement of Gay-Lussac and Thenard, that boron, when converted into boracic acid, only absorbs half its weight of oxygen, is most certainly extremely inaccurate. Davy's result, I believe to be about $\frac{1}{8}$th part below the truth; but the result of the French chemists cannot be much less than $\frac{5}{4}$ths below the truth.

In the second volume of the second series of the Annals of Philosophy, I published a set of experiments on boracic acid,—from which I deduced 2·75 as the probable atomic weight of that acid. But my experiments, which consisted in the analysis of borax, were not quite conclusive, owing to the difficulty of collecting and weighing the whole of the boracic acid. I had not at that time examined *fluoboric acid gas* with the requisite attention. I have since found, that this curious combination furnishes us with the means of determining the atomic weight of boracic acid with rigid accuracy.

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1. It will be proved in the 15th chapter of this treatise, that the weight of an atom of fluoric acid is 1·25. Fluoboric acid gas may be obtained by mixing together anhydrous boracic acid and pulverized fluor spar, and exposing the mixture to a red heat, in an iron tube—or simply, by heating in a retort (as was first discovered by Dr. John Davy), a mixture of 1 part boracic acid, 2 parts fluor spar, and 12 parts sulphuric acid. I collected a quantity of this gas, and took its specific gravity two different times, and obtained each time the very same result; namely 2·3709. Specific gravity of fluoboric acid gas.

On causing the gas under examination to be absorbed by water, I observed that there was a slight deposite of silica, indicating a mixture of fluosilicic gas. By weighing this silica, I determined the volume of fluosilicic gas, and on deducting it, the specific gravity of the fluoboric acid gas was 2·38833. A careful examination of the water containing the fluoboric acid gas, enabled me to detect in it the presence of a small quantity of sulphuric acid;—it was present to the amount of 0·8 grain in the hundred cubic inches of the gas. This being also deducted, the specific gravity of pure fluoboric acid gas became 2·3622.*

* Dr. Davy found the specific gravity of this gas 2·3709. This is the very specific gravity which I got—and a little above the truth, owing, doubtless, to a little fluosilicic or sulphuric acid, or both.

Its atomic weight.

2. Dr. Davy found that fluoboric acid gas and ammoniacal gas, combine with each other in the three following proportions:

(1) 1 volume fluoboric gas, 1 volume ammoniacal gas } forming a solid salt.

(2) 1 volume fluoboric gas, 2 volumes ammoniacal gas } forming a liquid.

(3) 1 volume fluoboric gas, 3 volumes ammoniacal gas } forming a liquid.

It will be shown in the 7th chapter of this treatise, that, in the greater number of gases, a volume of the gas represents an atom. But in ammoniacal gas this is not the case; two volumes of this gas are requisite to constitute an atom. It is reasonable to conclude from this, that the second of the preceding compounds is the one consisting of an atom of each constituent. We have it, therefore, in our power to determine the atomic weight of fluoboric acid from it.

1 volume fluoboric gas weighs	2·3622	or 4·2519
2 volumes ammoniacal gas -	1·18055	- 2·125

2·125 is the weight of an atom of ammonia; consequently, 4·2519 is the weight of an atom of fluoboric acid. The law of Dr. Prout, which will be found to hold in the atomic weights of all bodies, shows us that this number is a very little too high. The true atomic weight is undoubtedly 4·25; consequently, the true specific gravity

of fluoboric acid gas is 2·3611, which differs less than $\frac{1}{1000}$th part from the specific gravity which I actually obtained.

3. 4·25, then, is the atomic weight of fluoboric acid, and 1·25 is the atomic weight of fluoric acid; consequently fluoboric acid is a compound of Its composition.

Fluoric acid	1·25
Boracic acid	3·00
	4·25

3, then, is the weight of an atom of boracic acid; for Davy's experiments on the composition of boracic acid—Berzelius' analysis of borate of ammonia—and mine of borax—preclude the possibility of either more or less than an atom of boracic acid being united in fluoboric acid, with an atom of fluoric acid.

From Davy's analytical experiments, it is clear, that the atom of boron is 1; and that boracic acid is a compound of Atom of boron and of boracic acid.

1 atom boron	1
2 atoms oxygen	2
	3

4. It occurred to me, that, by heating together anhydrous boracic acid and dry carbonate of potash, some light might be thrown on the atomic weight of boracic acid, by the quantity Ratio between the weights of boracic and carbonic acids.

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of carbonic acid driven off. A quantity of carbonate of potash was fused in a platinum crucible, which varied in different experiments, from 80 to 100 grains; and 9 grains of anhydrous boracic acid being added, the fusion was usually continued from one hour to an hour and a half, or in one case, two hours. The loss of weight in the different experiments was not uniform. The smallest loss amounted to 6·8 grains, and the greatest to 8 grains. In these experiments it is obvious, that the greatest loss of weight must be nearest the truth. Even 8 grains, the maximum loss of weight, is a little below the real quantity of carbonic acid which ought to have been displaced. The reason of the variation in these results, and the difficulty of driving off the full quantity of carbonic acid, I take to be, that the boracic acid has a tendency to fall to the bottom of the fused mass, and to remain at the bottom. It is, therefore, difficult to bring the acid and the carbonate into contact, and to keep them in contact till the whole acid enters into combination with the potash and displaces the carbonic acid. I found that I succeeded best when I placed the acid on the surface of the alkali.

But let us see what the atomic weight of boracic acid will be, if we suppose 9 grains of it to saturate as much potash as 8 grains of carbonic acid. 8 : 9 : : 2·75 : 3·09375 = atomic weight

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of boracic acid. This number comes near 3, which we have seen to be the true atomic weight of boracic acid; and serves still farther to show that the experiments from which I deduced 2·75 to be its atomic weight, were inaccurate.

Bihydrate of boracic acid.

5. Boracic acid, as it is usually obtained from borax by precipitation, is in white opaque scales, containing a considerable quantity of water. Sir H. Davy, Berzelius, and myself, endeavoured to determine the quantity of water present in these scales. The experiment is attended with a good deal of difficulty. I varied my method after I became aware that my first experiments were wrong, and endeavoured to prevent any volatilization of boracic acid, by mixing the hydrous acid with a considerable quantity of protoxide of lead. But I still found the loss of weight to amount to 44 per cent. The following are the results of Davy, Berzelius, and myself. The hydrate is composed of

	DAVY.	BERZELIUS.	THOMSON.
Real acid	57	56	56
Water	43	44	44

I am satisfied that Davy came nearest the truth, though I have not been able to discover the cause of my own failure. If the hydrous acid contain two atoms of water united to one atom of acid, its constituents should be

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1 atom boracic acid	3	or 57·143
2 atoms water .	2·25	42·857
	5·25	100

which almost coincides with Davy's experiment.

Composition of borate of ammonia.

6. Very few of the borates have hitherto been analyzed, and very few of them accurately. However, from Berzelius' analysis of borate of ammonia, I think we are entitled to conclude that the salt is composed of

1 atom boracic acid	3
1 atom ammonia .	2·125
2 atoms water . .	2·25
	7·375

Berzelius obtained

Boracic acid	2·659
Ammonia	2·125
Water	2·25
	7·034

Analysis of borax.

7. It was not till I had satisfied myself of the true atomic weight of boracic acid from the specific gravity and combinations of fluoboric acid, that I became acquainted with M. Arfwedson's method of analyzing the borates by means of fluor spar. He mixes the borate to be analyzed with a determinate quantity of fluor spar reduced to the state of a very fine powder, and exposes the mixture with the requisite

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quantity of sulphuric acid to heat in a platinum crucible. The boracic acid is disengaged in the state of fluoboric acid, and the base of the borate remains combined with sulphuric acid. In the alkaline borates the base, when converted into a sulphate, is soluble in water, and may therefore be obtained in a separate state and its weight determined. I had recourse to this method, in order to determine the weight of soda in borax, my previous analysis of this salt having been obviously incorrect. (1.) 19 grains of borax being slowly raised to a red heat in a platinum crucible till they ceased to lose water, were found to have sustained a loss amounting almost exactly to 9 grains. (2.) 19 grains of borax, and 9·5 grains of very finely pounded fluor spar, intimately mixed together, were made up into a paste with sulphuric acid in a platinum crucible, and after digesting for 24 hours were exposed to a strong red heat. The matter remaining in the crucible was white, and weighed about 26 grains. This matter was digested in water, which dissolved the sulphate of soda, together with a little of the sulphate of lime. This water was mixed with oxalate of ammonia to throw down the lime. It was then filtered, evaporated to dryness, and the residual salt exposed to a red heat. It weighed within $\frac{1}{1000}$th part of 9 grains; indicating 4 grains of soda. Thus it appears, that 19 grains

of crystallized borax contain 4 grains of soda, and 9 grains of water. The 6 grains wanting to complete the whole weight, must represent the boracic acid in the salt. The reader will observe that the original weight of the ingredients put into the crucible (abstracting the water) was 19·5, consisting of

10 grains anhydrous borax
9·5 grains fluor spar

19·5

The boracic acid of the borax, and the fluoric acid of the fluor spar, had been driven off together, and these acids had been replaced by sulphuric acid. Now, 9·5 fluor spar are composed of

7·0 lime
2·5 fluoric acid

9·5

7 of lime require 10 of sulphuric acid for saturation. So that the sulphate of lime in the residue amounts to 17 grains. The remaining 9 grains are sulphate of soda, composed of

4 soda
5 sulphuric acid

9

But the original weight of anhydrous borax was 10, and it obviously contained 6 grains of bora-

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cic acid. Thus, all the parts of this experiment confirm eac h other, and show that borax is a compound of

2 atoms boracic acid	6
1 atom soda .	4
8 atoms water .	9
	19

8. Arfwedson has analyzed boracite by a similar process, and it follows from his analysis, that the mineral is a biborate of magnesia, and consequently a compound of Of boracite.

2 atoms boracic acid	6
1 atom magnesia	2·5
	8·5

This salt is perfectly anhydrous.

SECT. III.

OF THE ATOMIC WEIGHT OF SILICON.

Though the experiments of Sir H. Davy have satisfied chemists that silica is a compound of oxygen, and a dark coloured combustible substance, like carbon or boron, to which the name of *silicon* or *silicium* has been given; and though Berzelius has obtained silicon in a separate state; yet as silica is the only known compound

into which it enters, the principal object of inquiry in this section will be into the atomic weight of *silica*. This inquiry is of great importance; because upon it the exact knowledge of the constitution of most stony bodies depends. I am of opinion that the atomic weight of silicon is precisely 2, and I shall proceed to state the evidence upon which that opinion is founded.

Proofs that the atom of silica weighs 2.

Analysis of silica by Berzelius

I. In the year 1810, Berzelius published a set of experiments, containing an analysis of silica which he made in the following manner:* He mixed together determinate proportions of iron filings, silica, and charcoal in a crucible, and exposed the mixture, properly covered, to the greatest heat of a blast furnace. The united action of the iron and charcoal decomposed the silica, and the silicon as it was evolved, entered into combination with the iron. The silicious iron thus formed was whiter, and had a smaller specific gravity than common iron. When dissolved in muriatic acid, it gave out a greater proportion of hydrogen gas than common iron, and this hydrogen gas contained a certain proportion of carbon. It left undissolved a quantity of silica. He dissolved a given weight of this iron in muriatic acid, collected the hydrogen gas evolved, and by burning it over lime water determined the quantity of carbonic acid formed, from which he deduced the carbon

* Afhandlingar. III. 117.

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which the iron contained. The iron was then peroxydized, precipitated by ammonia, heated to redness, and weighed. The iron and carbon deducted from the original weight of the iron, gave the weight of the silicon which had been united with it. This silicon weighed 127 parts, but the *silica* obtained when the specimen was treated with muriatic acid, amounted to 335 parts. Now, 335 — 127 = 208 = the oxygen combined with 127 parts of silicon. But other experiments gave him silica composed of

Silicon	51·5 and 52·25
Oxygen	48·5 and 47·75

These experiments were repeated by Stromeyer,* who obtained for a result

Silicon	46·0069
Oxygen	53·9931

Now, the mean of these two sets of experiments gives us the composition of silica as follows :

Silicon	49·9189 or	0·9966
Oxygen	50·0811 —	1·0000
	100·0000	1·9966 = atomic weight of silica, which approaches exceedingly near 2.

Gives 1·9966 for the atom of silica.

Berzelius, in his essay on Chemical Proportions, and in the second edition of his *Lärbok i*

* Gilbert's Annalen. XXXVIII. 321

Kemien, states the composition of silica as follows:

Silicon	49·7	or	0·988
Oxygen	50·3		1·
	100·0		1·988 = atomic weight of silicon.

I do not know whether this new determination, which approaches the ratio of equality much more nearly than the number given by Berzelius in his original paper, be the result of a new set of experiments, or deduced from corrections made upon the old ones. But the atomic weight of silica deduced from it, is only $\frac{1}{166}$th part less than 2. And I do not believe it to be possible to operate in the way practised by Berzelius and Stromeyer, without the risk of a still greater error than $\frac{1}{166}$th part. I consider, therefore, this determination of Berzelius as a very strong evidence in favour of 2 being the true atomic weight of silica.

The composition of natural silicates.

II. Among the minerals which are found in regular crystals, and which have been subjected to chemical analysis, there are a good many containing silica united chemically, and consequently in definite proportions with different bases. If these minerals were perfectly pure, an accurate analysis of them would give us sufficient data for determining the atomic weight of silica. It will be worth our while to examine a few of these compounds, that we may see how

nearly they agree in giving the same atomic weight to this substance.

1. TABLE SPAR.

This mineral, which is a *bisilicate of lime*, or a compound of two atoms silica and one atom of lime, occurs in the Bannat. It has been observed likewise in Ceylon, constituting a part of the cinnamon stone rock. It has a greyish white colour, and a foliated fracture in one direction only, from which it has got its name. We have four analyses of this mineral; one by Klaproth, a second by Stromeyer, a third by Rose, and a fourth by Bonsdorff. Table spar

The specimens analyzed by Klaproth and Stromeyer were from the Bannat; those by Rose and Bonsdorff were found in Finland.

According to Klaproth, the constituents of table spar are

Silica	50
Lime	45·9*
Water	5
	100·9†

The constituents according to Stromeyer, are

* Klaproth reckons only 45; but he obtained 82 of carbonate of lime, which contains 45·9 lime.

† Beitrage, III. 289.

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Silica	51·445
Lime	47·412
Protoxide of iron	0·401
of manganese	0·257
Water	0·076
	99·591 *

Rose analyzed, in Berzelius' laboratory, a specimen of table spar from the village of Perheniemi in Finland, the constituents of which were

Silica	51·6
Lime	46·41
Oxide of iron, trace	
Actinolite	1·11
	99·12 †

The specimen analysed by Bonsdorff was from Pargas in Finland; it had been mistaken for tremolite. Its constituents were

Silica	52·58
Lime	44·45
Magnesia	0·68
Protoxide of iron	1·13
Volatile matter	0·99
	99·83 ‡

Before drawing any conclusion from these experiments, it may be proper to observe that in the Bannat, the table spar occurs in a rock consisting of garnets, blue limestone, and table spar.

* Untersuchungen, I. 356. † Nordenskiöld's Bedrage, 1st part, p. 94.
‡ Annals of Philosophy, (second series) II. 300.

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It is reasonable from this circumstance to expect, that the table spar analyzed by Klaproth and Stromeyer should contain a little too much lime, in consequence of the mixture of a small quantity of the blue limestone, with the portion of the mineral subjected to analysis. The iron and manganese, small quantities of which were detected by Stromeyer, no doubt originated from the garnets. The loss of five per cent. in Klaproth's analysis, which he ascribed to water, might possibly be owing to the presence of some blue limestone in the specimen.

The table spar from Perheniemi occurs in a limestone rock. This might lead to an excess of lime in the specimen analyzed by Rose. That from Pargas was mixed with pargasite and other varieties of horneblende, which might occasion a slight excess of silica in the specimen analyzed by Bonsdorff.

The iron, manganese, magnesia, &c. which occur in minute quantity in the mineral, may be neglected altogether as foreign matter. We shall attend only to the silica and the lime.

Let us suppose an atom of silica to weigh 2, and an atom of lime 3·5; and let us suppose table spar to be a bisilicate of lime: its constituents would be

Silica	4	or	53⅓
Lime	3·5		46⅔

Now, Klaproth's analysis gives us

Silica	53⅓
Lime	48·96

Stromeyer's gives us

Silica	53⅓
Lime	49·153

Rose's gives us

Silica	53⅓
Lime	47·969

Bonsdorff's gives us

Silica	53⅓
Lime	45·086

In the three first analyses there is an excess of lime; because the mineral analyzed was found in a limestone rock; in the last analysis by Bonsdorff, there is an excess of silica, because the table spar was from a horneblende rock. If we take a mean of all these analyses as likely to furnish a near approximation to the true composition of table spar, we obtain

Silica	53·33$\dot{3}$	or	3·905
Lime	47·792		3·5

It is obvious that this mean cannot be correct, because three of the specimens examined came from a limestone rock, and therefore were likely to contain an excess of lime, and only one from a horneblende rock, and likely to contain an excess of silica. However, we see that even from this mean, we get 3·908 for the weight of two atoms of silica, or 1·9525 for the weight of one atom.

If we take the mean of the first three analyses which contain an excess of lime, we get 48·694 for the quantity of lime united with 53⅓ silica. And taking the mean of this quantity, and of 45·086, the lime united to the silica, according to Bonsdorff's analysis, we get 46·89 for the lime. This gives us table spar composed of

Silica	53·333	or	3·936
Lime	46·890	-	3·5

By this constitution (which is as near the truth as the accuracy of the analysis will admit) two atoms of silica weigh 3·936, and consequently, the weight of one atom is 1·968. Gives 1·968.

2. SILICATE OF ALUMINA, OR BUCHOLZITE.

Some years ago, a mineral was found in the Tyrol, to which Weiss gave the name of *fibrous quartz*, but Brandes, who analyzed it, distinguished it by the appellation of *bucholzite*. It has a white colour, interspersed with black spots; its texture is fibrous, and it has never been met with in crystals. Its constituents, according to the analysis of Brandes, are as follows: Bucholzite

Silica	46
Alumina	50
Oxide of iron	2·5
Potash	1·5
	100·0 *

* Schweigger's Jour. XXV. 125.

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Let us calculate the composition of this mineral, on the supposition that the silica is combined with three bases, atom to atom; and that an atom of silica weighs 2, an atom of alumina 2·25, an atom of protoxide of iron 4·5, and an atom of potash 6.

1. 2·25 (an atom of alumina): 2 (an atom of silica): : 50 (alumina in the mineral): = silica united to the alumina.	44·44̇
2. 4·5 (atom of protoxide of iron): 2 : : 2·5 (oxide in the mineral): = silica united to the iron	1·1̇1̇
3. 6 (atom of potash): 2 : : 1·5 (potash in the mineral): = silica united to the potash	0·5̇0̇
Total silica in the mineral =	46·05̇

This exceeds the quantity found by Brandes by only 0·05̇ grain—a quantity so small, that it might very easily be overlooked in an analysis. Let us, however, suppose, that the analysis is perfectly accurate, and let us deduce from it the atomic weight of the silica. About $\frac{1}{28}$th of the silica is united to the oxide of iron and the potash. Now, the 28th part of 0·05̇, the excess of silica, is nearly 0·002, which being deducted, leaves about 0·053. If we subtract this excess from the 44·44̇ of silica, supposed above to be united to the alumina, there will remain 44·391 grains. Hence, by Brandes' analysis of this mineral, silicate of alumina is composed of

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Silica	44·391	or	1·997595
Alumina	50	-	2·25

Thus the atomic weight of silica, from the analysis of bucholzite, comes out below 2; but the deficiency does not amount to $\frac{1}{800}$th part—a difference greatly within the limits of unavoidable error in such analyses.

3. NEPHELINE.

This mineral, which is found on Monte Somma, near Naples, has been long known to mineralogists. It crystallizes in six sided prisms, often bevelled at their extremities; it is hard enough to scratch glass, and has a specific gravity of 2·2741. From the late analysis of this mineral by Arfwedson, its constituents appear to be Nepheline

Silica	.	44·11
Alumina		33·73
Soda	.	20·46
Water	.	0·62
		98·92*

Let us suppose that in this mineral every atom of alumina is combined with an atom of silica; and every atom of soda with an atom and a half of silica, (this is a common mode of combination of soda with acids;)—and let an atom of silica weigh 2, an atom of alumina 2·25, and an atom of soda 4. Let us calculate the composi-

* Kongl. Vetenskaps Acad. Handl. 1821. p. 150.

tion of nepheline according to these suppositions:

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 33·73 (alumina in mineral) : . . . 29·98
= silica united to the alumina.

(2.) 4 (atom of soda) : 3 ($1\frac{1}{2}$ atom silica) : : 20·46 (soda in mineral) : . . . 15·345
= silica united to soda.

Total silica . . . . 45·325

The silica in the mineral being only 44·11 grains, is less than the amount of the silica deduced from the above suppositions by 1·215 grain. Let us admit the specimen analyzed by Arfwedson to have been perfectly pure, and the analysis to have been accurate, and let us deduce from it the atomic weight of silica.

It is obvious that nepheline must consist of 3 integrant particles of silicate of alumina, united to 1 integrant particle of sesquisilicate of soda. Of consequence, $\frac{1}{3}$d of the deficiency belongs to the sesquisilicate of soda. Hence, silicate of alumina, according to Arfwedson's analysis, is composed of

Gives 1·94582.	Silica	.	29·17	or 1·94582
	Alumina	.	33·73	- 2·25

The atom of silica deduced from this mineral is less than when deduced from bucholzite. The reason is, probably, that the substances with

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which the nepheline is mixed, (hornblende, meionite, &c.) introduce a slight excess of alumina, or soda, by destroying the rigid purity of the mineral.

4. HEDENBERGITE, OR TRISILICATE OF IRON.

Hedenbergite

This mineral occurs in Marmor's mine, Tunaberg, Sweden, where it forms layers in white calcareous spar. It was described and analyzed by M. Hedenberg, in the year 1807.* It has a blackish green colour, a fibrous fracture, and it seems to consist of rhombs, having the same figure as calcareous spar ;—phosphoresces both by heat and friction ;—specific gravity, 3·154. The constituents assigned by Hedenberg, but corrected by Berzelius, are

Silica . . .	40·62
Protoxide of iron .	32·53
Water . . .	16·05
Carbonate of lime .	4·93
Oxide of Manganese .	0·75
Alumina . . .	0·37
	95·25†

The carbonate of lime may be left out of view, because it is obviously derived from the rock in which the hedenbergite was found.

* Afhandlingar, II. 164. † Nouveau Systeme, p. 31.

Let us calculate the composition of hedenbergite, on the supposition that it is a trisilicate of iron; that silica weighs 2, and protoxide of iron 4·5.

4·5 (atom of protoxide of iron) : 6 (3 atoms silica) : : 32·53 : 43·37 = silica united to the iron.

The quantity of silica united to the iron (on the supposition that an atom of it weighs 2) exceeds the quantity in the mineral by 2·75 grains; but, in all probability, the oxide of manganese and the alumina supplied the place of the deficient silica. Now, 0·37 alumina will go as far in saturating oxide of iron, as 0·328 of silica; and 0·75 of protoxide of manganese will go as far as 0·333 of silica. We may, therefore, subtract 0·66 from the deficient silica, thus reducing the deficiency to 2·09 grains.

If we suppose the analysis perfectly correct, the composition of trisilicate of iron deduced from it will be

Silica	41·28	or	5·7104
Protoxide of iron	32·53	-	4·5

Gives 1·9035.

According to this analysis, 3 atoms of silica weigh 5·7104; hence the atom of silica is $\frac{5·7104}{3}$ = 1·9035.

5. DIOPTOSE, OR SESQUISILICATE OF COPPER.

Dioptose

This mineral, which was at first confounded

with the emerald, is usually crystallized in six-sided prisms, terminated by trihedral pyramids. It has a fine green colour, a foliated texture, and a specific gravity of 3·3. It is a conductor of electricity. From an analysis of this mineral by Lowitz, we learn that its constituents are

Silica . .	33
Peroxide of copper .	55
Water . .	12
	100

Let us calculate the constituents of this mineral on the supposition that it is a hydrated sesqui-silicate of copper; that an atom of silica weighs 2, an atom of oxide of copper 5, and an atom of water 1·125.

(1.) 5 (atom of oxide of copper) : 3 (1½ atom silica) : : 55 : 33 = the silica united to the oxide.

(2.) 88 : 12 (water in mineral) : : 8 : 1·0905 = water in the mineral, very nearly 1 atom.

Hence the mineral is composed of

1 integ. part. of sesquisilicate of copper	silica 33, oxide 55	88
1 atom water		12·37
		100·37

This mineral gives us exactly 2 for the atomic weight of silica. There is a slight deficiency in Gives 2.

the water, which could be probably accounted for, if we knew the previous treatment which the mineral had received.

6. SILICATE OF ZINC.

Silicate of zinc

This mineral was first accurately described and examined by Mr. Smithson. It is easily distinguished from the other *calamines*, by the property which it has of becoming electric when heated, which is peculiar to it. It is also very generally, if not always, in crystals.

According to Smithson's experiments, published in 1803, its constituents are

Silica . .	25
Oxide of zinc .	68·3
Water . .	4·4
	97·7

Berzelius, who made an analysis of it, expressly with a view to elucidate the doctrine of definite proportions, found it a compound of

Silica . .	24·893
Oxide of zinc .	66·837
Water . .	7·460
Carbonic acid .	0·450
Oxides of lead and tin	0·276
	99·916 *

* Nouveau Systeme Mineral. p. 258.

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An atom of oxide of zinc, as has been proved in the first chapter of this work, weighs 5·25. Now, if silica weigh 2, and this mineral be a silicate of zinc, we have 2 : 5·25 : : 24·893 : 65·344 = oxide of zinc united to the silica.

The oxide of zinc in the mineral exceeds this quantity by 1·493 grain, according to Berzelius' analysis. Let us see how far this excess can be accounted for.

1. The water in the mineral amounts, we see, to 7·460 per cent. Now, an atom of water weighs 1·125, and an integrant particle of anhydrous silicate of zinc 7·25; and 7·25 : 1·125 : : 90·237 (the silicate of zinc per cent.) : 14·002 = quantity of water, supposing the silicate to contain 1 atom water. Now, 14·002 being nearly double the quantity of water actually contained in the mineral, it is obvious that the silicate of zinc can contain only half an atom of water, which, in 100 parts of the mineral, amounts to 7·001. The quantity of water in the mineral is 7·460, which exceeds 7·001 by 0·459.

2. Besides the silica, then, there are two other substances contained in the mineral, both of which have the property of uniting to oxide of zinc. There are 0·459 grain of water, and 0·45 grain carbonic acid.

Now, 0·45 grain of carbonic acid requires 0·86 grain of oxide of zinc to form anhydrous carbonate; but carbonate of zinc usually contains 1½

atom of water. This, united to a quantity of anhydrous carbonate, weighing 1·31 grain, amounts to 0·276 grain. There still remains 0·183 grain of water to be disposed of. It is probably united with oxide of zinc in the mineral, so as to form the common hydrate of zinc, composed of 1½ atom water, united to 1 atom of oxide of zinc. Now, 1·6875 (1½ atom of water) : 5·25 (an atom of oxide of zinc) : : 0·183 (water still unaccounted for) : 0·569 = oxide of zinc united to this water, in the state of hydrate.

3. Thus it appears, that 1·429 grain of oxide of zinc may have been in the state of carbonate, or hydrate of zinc, reducing the amount of the surplus to 0·064 grain—a quantity greatly within the limits of the unavoidable errors of analysis.

We are entitled, therefore, to consider silicate of zinc as a compound of

Gives 1·998.	Silica . .	24·893	or	1·998
	Oxide of zinc .	65·408	-	5·25

Here the atomic weight of silica is about $\frac{1}{1000}$th part less than 2.

7. BISILICATE OF MANGANESE.

Bisilicate of manganese

This mineral is found at Longbanshytta, in Wermeland, Sweden; and it is said to occur

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more abundantly at Catherinburgh, in Siberia. It has a rose red colour, and has never been observed crystallized; but it has a foliated fracture, and natural cleavages, indicating a rhomboid for its primitive form. Its specific gravity, as determined by Hisinger, is 3·5384.

This mineral was analyzed by Ruprecht, and likewise by Napioni; but at a time when the chemical knowledge of manganese was not far enough advanced to admit of correct results. It was analyzed by Berzelius in 1806, and the constituents were published by him in the first volume of the *Afhandlingar* (p. 108). He repeated the analysis in 1817, with as much care as possible, and obtained the following constituents:

Silica . . .	48
Deutoxide of manganese	54·42
Lime . . .	3·12
Magnesia	0·22
With a trace of iron.	
	105·76

Here the weight of the ingredients exceeds the weight of the original specimen by 5·76. The reason is obviously, that, in the mineral, the manganese exists in the state of protoxide; but it was converted into deutoxide in the course of the analysis. It will be shown hereafter, that protoxide of manganese weighs 4·5, and deutox-

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ide 5. If we reduce the weight of the manganese in that proportion, the constituents of the mineral become

Silica . . .	48
Protoxide of manganese	48·98
Lime . . .	3·10 *
Magnesia . . .	0·22
	100·3

Let us consider this mineral as a bisilicate of manganese; and let us calculate its composition, on the supposition that an atom of silica is 2, an atom of protoxide of manganese 4·5, an atom of lime 3·5, and an atom of magnesia 2·5.

(1.) 4·5 (atom of protoxide manganese) : 4 (2 atoms silica) : : 48·98 : 43·53 = silica united to manganese	43·53
(2.) 3·5 (atom lime) : 4 : : 3·1 : 3·54 = silica united to lime	3·54
(3.) 2·5 (atom magnesia) : 4 : : 0·22 : 0·35 = silica united to magnesia	0·35
Total silica united to the bases =	47·42

This quantity of silica is 0·58 grain less than what was found in the mineral by Berzelius. The quantity which he found is $\frac{1}{120}$th part more than it ought to have been, supposing an atom of silica to weigh 2. Let us, therefore, deter-

* Correcting Berzelius's estimate.

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mine the atomic weight of silica, on the supposition that the constituents, as determined by Berzelius, are rigidly accurate.

The bisilicates of lime and magnesia may be omitted as foreign bodies. They contain about $\frac{1}{12}$th of the whole silica; consequently, $\frac{1}{12}$th of the surplus silica, or 0·05, must be subtracted. The remainder is 0·53: let us add this to the silica united to the protoxide of manganese. This gives us bisilicate of manganese composed of

Silica . . .	44·06	or 4·04798
Protoxide of manganese	48·98	- 4·5

Two atoms of silica weigh 4·04798; consequently, the weight of an atom will be 2·02399, which exceeds 2 by rather more than 1 per cent. Gives 2·024.

8. KNEBELITE, OR SILICATE OF IRON AND MANGANESE.

This ore has been described and analyzed by Dobereiner. It is grey, with spots of various colours, occurs in amorphous masses, and has a specific gravity of 3·714. According to Dobereiner's analysis its constituents are Knebelite

Silica . . .	32·5
Protoxide of iron .	32
Protoxide of manganese	35
	99·5

Let us calculate the composition of this mineral on the supposition that it is a silicate of iron and manganese; and that the atomic weight of silica is 2, of protoxides of iron and manganese, each 4·5.

(1.) 4·5 (protoxide of iron atom) : 2 (atom of silica) : : 32 : 14·2̇2̇ = silica united to oxide of iron 14·2̇2̇

(2.) 4·5 (atom of protoxide of manganese) : 2 : : 35 : 15·5̇5̇ = silica united to the oxide of manganese 15·5̇5̇

Total silica united with the bases = 29·7̇7̇

The silica found in the mineral by Dobereiner exceeds this quantity by 2·72 grains. This excess might be ascribed to the presence of a certain quantity of trisilicate of manganese. Protoxides of iron and manganese having the same atomic weight, the silicates of these two bases should have the same weight. Hence, it is not unreasonable to suppose, that only 32 grains of the protoxide of manganese were in the state of silicate—the other 3 grains may have existed in the state of trisilicate. Now, 4·5 (atom of protoxide of manganese) : 6 (3 atoms silica) : : 3 : 4 = silica united to the 3 manganese. The constituents of the mineral may be thus stated:

Silicate of iron .	46·2̇2̇
Silicate of manganese	46·2̇2̇
Trisilicate of manganese	7·00
	99·4̇4̇

This almost coincides with the analysis of Dobereiner.

But waving this probable explanation of the excess, let us calculate the atomic weight of silica, on the supposition that the mineral contains only simple silicates, and that the analysis is quite correct. The excess of the silica must be divided between the two silicates in the ratio of $14{\cdot}2\dot{2}$: $15{\cdot}5\dot{5}$; or we must add 1·42 of it to the silica united to the manganese, and 1·3 to the silica united to the iron. This gives us silicate of iron composed as follows:

			Gives
Silica . .	15·52	or 2·1827	2·1827.
Protoxide of iron	32	- 4·5	

Let us now take a mean of the weight of an atom of silica, deduced from the analyses of the 8 minerals which we have just examined.

1	Table spar gives the atom of silica	1·96800
2	Bucholzite	1·997595
3	Nepheline	1·94582
4	Hedenbergite	1·90350
5	Silicate of zinc . . .	1·99800
6	Dioptase	2·00000
7	Bisilicate of manganese . .	2·02399
8	Knebelite	2·18270
	Mean	2·00245

Mean 2·00245.

This weight exceeds 2 only by $\frac{1}{1000}$th part. The atomic weight given by Berzelius, from his own

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experiments, is below 2. But the weight just deduced is from a much greater number of experiments, and ought, therefore, to be much nearer the truth.

Ratio between the atom of silica and carbonic acid

III. It occurred to me, that, as silica, when heated with carbonate of potash, has the property of disengaging the carbonic acid gas and uniting with the potash in its place, I might be able to form some estimate of the atomic weight of silica by mixing determinate quantities of it with pure dry carbonate of potash, exposing the mixture to a strong heat in a platinum crucible, and noting the loss of weight.

I found, in the first place, that carbonate of potash, obtained by exposing crystals of the bicarbonate to a red heat, lost no sensible weight though kept for a considerable time in a state of fusion. I found, in the second place, that, to make a successful experiment, it was necessary to employ, at least, eight times as much carbonate of potash as of silica. When less was employed, the loss of weight was always much too small. Twelve grains of pure silica in fine powder, and anhydrous carbonate of potash, were mixed together, and kept in a state of fusion for 13 hours in a platinum crucible. The loss of weight amounted to 16·67 grains.

It appears from this experiment, that 16·67 grains of carbonic acid are displaced by 12 grains of silica: but upon examining the cruci-

ble, I found that it had become lighter by 0·15 grain. Deducting this diminution, there remain 16·52 grains for the true quantity of carbonic acid expelled. Now 16·52 (the carbonic acid expelled) : 12 (the silica employed) : : 2·75 (the atomic weight of carbonic acid) : 1·99758 ∴ = the weight of an atom of silica. Gives 1·99758 for the atom of silica.

From this experiment, which was several times repeated, the atom of silica appears to weigh 1·99758, which is very nearly $\frac{1}{1000}$th part less than 2;—the atomic weight of silica, deduced from the analysis of eight silicates, was a little above 2. As the deviations in these two different sets of experiments are on different sides, there is a chance that the mean of the two may come still nearer the truth.

Atomic weight of silica from the analysis of eight silicates	2·00245
Atomic weight of silica from heating silica and carbonate of potash	1·99758
Mean of both	2·00001

Mean of both gives 2·00001.

This atomic weight is little more than $\frac{1}{200.000}$th part greater than 2.

IV. Silica enters into definite combinations with water, forming various hydrates. Some of these I have examined with care; and they furnish satisfactory evidence that the true atomic weight of silica is 2.

1. When silica is fused with potash or car-

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Dihydrate of silica.

bonate of soda, and the fused mass digested in hot water, we may either obtain a solution, or a white insoluble flocky residue may be left, according to the quantity of water which we employ. This flocky residue is a hydrate of silica, which may be separated by the filter, washed by repeated effusions of water, and dried in a temperature which must not exceed 85° or 90°. In summer, when the weather happened to be very warm, I have repeatedly obtained an accurate atomic hydrate of silica by drying it in the open air; but in general, unless the temperature be artificially raised, the silica retains a small excess of water. This hydrate, when properly prepared, is composed of

Silica . .	4
Water . .	1·125
	5·125

Now, 1·125 is 1 atom of water, and 4 must be just 2 atoms of silica; so that the hydrate is a compound of 1 atom water, and 2 atoms silica; and an atom of silica weighs exactly 2.

I shall relate two experiments which I made to obtain this hydrate,—the first an unsuccessful, and the second a successful one,—that the reader may be enabled to judge how great a surplus of water the silica may retain.

About the middle of May, 1823, I fused a

quantity of silica, with thrice its weight of anhydrous carbonate of soda, and digested the fused mass in a small quantity of water, till the silica assumed a flocky appearance. The whole was then thrown upon a filter; and the silica was washed repeatedly with distilled water, till no traces of soda could be found in the washings. In two days the filter with the silica became dry enough to be handled. I placed the filter on several folds of bloating paper, on a table in the middle of my laboratory, where it was allowed to remain for six weeks, without being disturbed. It may be necessary to mention, that the weather during the whole time was uncommonly cold; and I have reason to believe, that the temperature of the room scarcely ever exceeded 60°, if it amounted to so much. When I returned to Glasgow, on the 24th of June, the thermometer in my laboratory stood at 57°. The silica, to the eye and the feel, appeared perfectly dry; it weighed 43·23 grains. By exposure to a red heat, it lost 10·55 grains, and was reduced to 32·68. Now, 32·68 : 10·55 : : 4 : 1·2913 = water combined with 4 silica. This exceeds 1·125 by 0·1663, which is rather more than ⅙th of an atom. This may be considered the greatest amount of the excess which ever remains. I shall now state the circumstances of the successful experiment.

A quantity of silica obtained, precisely as in

the preceding experiment, after being sufficiently washed was left on the filter till it was dry enough to be moved. It was then placed (still on the filter) in a linen bag, which was suspended at some height above my sand bath, in a temperature of 85°, where it was left for several days, till it ceased to lose weight. By this treatment, the silica became a very white, dry powder, which weighed 38·4 grains. Being exposed to a red heat, the weight was reduced to 29·97 grains; so that it had been a compound of 29·97 silica, and 8·43 water. Now, 29·97 : 8·43 : : 4 : 1·125 = the water united to 4 of silica. Here we see that the silica and water were united in the true atomic proportions. And this is an experiment which I have often made successfully.

Thirteenth hydrate of silica.

2. If the silicated potash, or soda, be digested in a sufficient quantity of water, we may obtain a complete solution, which is neither precipitated by acids nor alkalies. When this solution is concentrated by evaporation, it assumes the form of a transparent, colourless, tremulous jelly, consisting of silica and water, united together in the form of a hydrate. If we throw this jelly upon the filter, and wash it with hot water till the alkali be completely removed, the silica remains in the state of a matter, so transparent and colourless, as scarce to be perceptible at first. If we allow this jelly to dry on the filter till it ceases to feel wet, or to moisten bibulous paper, it still

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retains a certain degree of transparency, and is not quite destitute of its gelatinous form. In this state it is a compound of

1 atom silica	.	2
13 atoms water	.	14·625
		16·625

So that in this hydrate, though apparently quite dry and solid, more than $\frac{8}{9}$ths of the whole weight is water.

3. If we allow this solid mass of jelly to dry in the open air, without breaking it in pieces, it gradually assumes a yellowish colour, somewhat similar to that of gum-arabic; and even after an interval of several years, it is still semi-transparent. In this state it is very brittle, but hard, and breaks with a conchoidal fracture. It has a certain resemblance to common flint; or rather it may be stated as an intermediate looking substance between flint and calcedony. This hydrate of silica, when successfully prepared, is composed of Hydrate of silica.

1 atom silica	.	2
1 atom water	.	1·125

I have succeeded in preparing this hydrate, only by leaving it for a very long time (in general several years) in a warm and dry room. I shall state the result of an experiment made during the summer of 1823. A quantity of gelatinous

silica, prepared in the way just described, was left, unbroken, on the filter, for six weeks. Its weight was 13·63 grains, Being exposed to a red heat, it lost 5·13 grains; consequently, the anhydrous silica amounted to 8·5 grains, and the water to 5·13. Now, 8·5 : 5·13 : : 2 : 1·207 = water united to 2 silica. This exceeds the atomic proportion by about $\frac{1}{14}$th of an atom.

Other hydrates.

4. There are several other hydrates of silica, besides the three which I have just described. I have formed a hydrate, composed of

3 atoms silica	= 6
1 atom water	= 1·125
	7·125

I have obtained another, composed of

4 atoms silica	= 8
3 atoms water	= 3·375
	11·375

This great variety of hydrates renders it always indispensable in the chemical analysis of minerals to expose the silica to a red heat, in order to be sure of its true weight.

Conclusions.

V. The details in this section have been somewhat tedious; but they were necessary to establish the true atomic weight of silica. Let us recapitulate the different results obtained.

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1. Berzelius has concluded from his analysis of silicated iron, that the atomic weight of silica is 1·988. But the mean of the experiments of Berzelius and Stromeyer gives us for its atomic weight 1·9966.

2. The mean of the analysis of eight native silicates of different kinds gives us the atomic weight of silica 2·00245.

3. My decomposition of carbonate of potash by silica gives for its atomic weight 1·99758.

4. The analysis of the hydrates of silica gives its atomic weight exactly 2.

Even if we were to strike a mean from all these different estimations, the weight of an atom of silica would not deviate so much as $\frac{1}{1000}$th part from 2. But this method of proceeding would not be quite proper. The experiments on the hydrates being most easily made, and most susceptible of precise results, should have the greater effect in fixing our notions on the subject. Now, the hydrates make the atomic weight of silica precisely 2. Next to the hydrates, the greatest confidence seems due to the mean deduced from the analysis of the eight silicates; now, this mean differs from 2 by only $\frac{1}{1000}$th part. Upon the whole I am persuaded, that no unprejudiced person who peruses the preceding details can have any doubt that the true atomic weight of silica is 2.

Silica is a compound of silicon and oxygen.

Now, from the experiments of Berzelius, mentioned in the beginning of this section, it is clear that the weights of the silicon and oxygen are nearly equal. Since the atomic weight of silica is 2, and of oxygen 1, it is evident that the atomic weight of silicon is also 1. The true composition of silica is therefore

1 atom silicon	1
1 atom oxygen	1
	2

SECT. IV.

OF THE ATOMIC WEIGHT OF PHOSPHORUS.

PHOSPHORUS enters into chemical combinations both with hydrogen and oxygen; with the former it constitutes only gaseous, with the latter, only solid compounds. Its combinations with oxygen are *phosphorous* and *phosphoric acids*—combinations of great importance in the animal, and not without interest in the mineral kingdom. Let us first investigate the atomic weight of phosphoric acid. It will then be easy to determine the composition of phosphorous acid.

Atomic weight of phosphoric acid

1. Phosphoric acid forms soluble and crystallizable salts with the alkalies. Of these none is better known than phosphate of soda, which being employed as a medicine, is prepared by

trading chemists, and kept for sale in apothecaries' shops.

It crystallizes in rhomboids, has a cooling and somewhat bitter taste, and effloresces when kept in a dry atmosphere. I have met with this salt consisting of 11 atoms, and likewise of 12 atoms of water combined with one integrant particle of anhydrous phosphate of soda. By far the most common proportion of water, however, is 12 atoms. This difference in constitution, as far as the aqueous part is concerned, probably depends upon the way in which it has been kept. It very speedily effloresces when exposed to the air. Now, when got from the shops, we often perceive white effloresced spots scattered through the crystals. It is in such cases that the water of crystallization is sometimes reduced to 11 atoms. We can never depend upon the water of crystallization, unless the salt be quite transparent. I think it best to make it anhydrous by heating it red hot, and keeping it for some time in a state of fusion in a platinum crucible.

7·5 grains of anhydrous phosphate of soda, and 20·75 grains of crystallized nitrate of lead, were dissolved in separate portions of distilled water, care being taken not to employ more water than was sufficient to dissolve the salts completely. These two solutions being mixed together, a double decomposition took place; phosphate of lead precipitated in the state of a

white insoluble powder, while a transparent colourless liquid remained, holding nitrate of soda in solution. A drop of this liquid was put into a watch glass, and mixed with a drop of solution of sulphate of soda. No precipitation or opalescence took place, showing that the liquid contained no sensible quantity of lead. Another drop of the same liquid being put into another watch glass, was tested in the same manner with nitrate of lead, without being in the least affected, showing the absence of any sensible quantity of phosphoric acid. This experiment was repeated several times with exactly the same result.

From the preceding experiment it is obvious, that the oxide of lead in 20·75 grains of nitrate of lead, just neutralizes the phosphoric acid in 7·5 grains of anhydrous phosphate of soda. In like manner, the nitric acid of the former salt just neutralizes the soda of the latter. But 20·75 grains of nitrate of lead are composed of

Nitric acid .	6·75
Protoxide of lead	14
	20·75

Numbers which are equivalent to the atomic weights of nitric acid and protoxide of lead.

Fourteen grains of protoxide of lead require for saturation, a quantity of phosphoric acid, equivalent to an atom; 6·75 grains of nitric

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acid require exactly 4 grains of soda, which will be shown afterwards to be equivalent to an atom.

7·5 grains of anhydrous phosphate of soda, then, contain just 4 grains of soda. The remaining 3·5 grains must be the phosphoric acid of the salt. Thus, it appears, that anhydrou phosphate of soda is composed of

Phosphoric acid	3·5
Soda . .	4·0
	7·5

Shown to be 3·5.

3·5 of phosphoric acid just saturate 4 of soda, and 14 of protoxide of lead, each of which numbers, represents the atomic weight of the respective bases; consequently, 3·5 is the atomic weight of phosphoric acid.

Attempts to analyze phosphoric acid.

2. Many attempts have been made by chemists to determine the composition of phosphoric acid by the rapid combustion of phosphorus. For when phosphorus burns with flame, it unites with the oxygen of the atmosphere, and is converted into phosphoric acid. Now, as both phosphorus and phosphoric acid are solids, it appears at first sight easy to determine the quantity of oxygen with which the phosphorus has combined, merely by weighing the phosphoric acid produced. But in reality, this method, though apparently easy, is not susceptible of perfect accuracy. Phosphorus can scarcely be obtained

in a state of complete purity, and we have no means of appreciating the proportion of impurities with which it is contaminated. It can hardly be burned completely in close vessels, always leaving behind an orange coloured matter, which deliquesces in the air, and is gradually acidified spontaneously. It would be needless to relate the experiments made in succession in this way, by Lavoisier, Rose, myself, Dulong and Berzelius. Sir Humphrey Davy had the sagacity to obviate some of the difficulties that had proved most perplexing to his predecessors, and his experiments came by far the nearest to the truth, though they did not altogether reach it. It may be worth while, therefore, to mention the result of his researches on this difficult subject.

He inclosed the phosphorus in a separate tray, which he introduced into the belly of a glass retort; by this contrivance, he was enabled to give a stronger and longer continued heat to the phosphorus. He found that 100 parts of phosphorus, when converted into phosphoric acid, unite with 135 parts of oxygen. Let us deduce the atomic weight of phosphoric acid from this composition.

It is obvious, that this acid is a compound of one atom of phosphorus with one or more atoms of oxygen. Were the quantity of oxygen only one atom, the atomic weight of phosphoric acid would be only 1·74. For 135 (the oxygen in

the acid) : 100 (the phosphorus in the acid) : : 1 (an atom of oxygen) : 0·74074 = atomic weight of phosphorus. But we have just seen that its true atomic weight is 3·5.

Let us suppose the quantity of oxygen to be two atoms. This would make the atomic weight of phosphoric acid 3·481. For 135 : 100 : : 2 : 1·4815 = atomic weight of phosphorus.

It appears from this, that phosphoric acid is a compound of two atoms oxygen, and one atom phosphorus; and that the atomic weight of phosphorus, according to the result of Davy's experiments, is 1·4815. But we have seen that phosphoric acid weighs 3·5; therefore, the atom of phosphorus must in fact weigh 1·5, or nearly 2 per cent. more than results from Davy's synthetic experiment. Hence, 100 phosphorus must combine with only 133⅓ of oxygen, to form phosphoric acid; for 133⅓ : 100 : : 2 : 1·5. That this is the true composition of the acid will appear from the following experiments.

3. Phosphorus and hydrogen combine in two proportions, and form two gaseous compounds called *phosphuretted hydrogen*, and *bihydroguret of phosphorus*; the former of which was first distinguished as a peculiar substance by M. Gengembre, the latter by Sir Humphrey Davy.

(1.) Phosphuretted hydrogen gas may be obtained pure, by putting fresh phosphuret of lime into a small retort, filling the retort with water, Composition of phosphuretted hydrogen.

and plunging its beak into a trough containing recently boiled water, or water in which some deutoxide of azote has been agitated; the gas is extricated with considerable rapidity; it is colourless, has a smell somewhat similar to that of garlic, and takes fire spontaneously when it comes in contact with common air. Water absorbs about 5 per cent. of its volume of it. The specific gravity of this gas from a mean of some very careful experiments made in my laboratory, is 0·902735. But I have elsewhere shown that its true specific gravity is 0·90277;* which exceeds the experimental result by an almost inappreciable quantity.

When phosphorus is heated in hydrogen gas, a portion of phosphuretted hydrogen gas is formed; but the volume of the original gas is not increased. It is obvious from this, that a volume of phosphuretted hydrogen gas contains just a volume of hydrogen gas. Hence, if from the specific gravity of phosphuretted hydrogen gas we subtract the specific gravity of hydrogen gas, the remainder will represent the weight of phosphorus united to a volume of hydrogen gas.

Sp. gr. of phosphuretted hydrogen gas	0·90277
——————— hydrogen gas	0·06944
Phosphorus . . . . =	0·83333

* Annals of Philosophy, XVI. 262.

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Thus it appears, that phosphuretted hydrogen gas is a compound of

Hydrogen	0·0694	or	0·125
Phosphorus	0·8333	-	1·5

But 0·125 represents the weight of an atom of hydrogen, and 1·5 must be the weight of an atom of phosphorus. The gas is obviously a compound of one atom hydrogen, and one atom phosphorus.

If we mix together one volume of phosphuretted hydrogen gas with either one volume or 1·5 volume of oxygen gas, combustion takes place, and the whole gaseous mixture disappears, being in the first case condensed into water and phosphorous acid, and in the second, into water and phosphoric acid. Let us analyze these combustions ; they will give us the composition of both phosphorous and phosphoric acids.

A volume of phosphuretted hydrogen gas may be considered as composed of one volume hydrogen gas, and one volume phosphorus vapour condensed into one volume—and a volume both of hydrogen gas and of phosphorus vapour is equivalent to an atom. The volume of hydrogen, in order to be converted into water, requires half a volume of oxygen gas. It is obvious from this, that phosphorous acid is a compound of one volume phosphorus vapour and half a volume of oxygen gas ; and phosphoric

acid of one volume phosphorus vapour and one volume oxygen gas. But one volume of phosphorus vapour, and half a volume of oxygen gas being each equivalent to an atom, it is obvious, that the constitution of these two acids is the following:

Atom of phosphorous acid.

1. PHOSPHOROUS ACID.

1 atom phosphorus	= 1·5
1 atom oxygen .	= 1

2·5 = atomic weight of acid.

2. PHOSPHORIC ACID.

1 atom phosphorus	= 1·5
2 atoms oxygen .	= 2

3·5 = atomic weight of acid.

Thus an atom of phosphorous acid weighs 2·5, and an atom of phosphoric acid 3·5, which is precisely the weight deduced in the beginning of this section, from the analysis of phosphate of soda.

Subphosphuretted hydrogen gas.

When this gas is allowed to stand for some days over mercury or water, it undergoes no sensible alteration in its volume, but deposites one-fourth of its phosphorus. When thus altered, it does not catch fire when mixed with common air, or oxygen gas; but combustion may be immediately induced, by letting up into it a little deutoxide of azote. When sulphur is sublimed

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in it, no alteration takes place in its volume. For complete combustion, 1 volume of this altered gas requires 1·25 volume of oxygen gas. By the combustion, it is converted into water and phosphoric acid. Complete combustion cannot be induced with any smaller volume of oxygen gas. When we pass an electric spark through a mixture of 1 volume of the gas, and 0·75 volume of oxygen gas, a detonation takes place; but the residual gas occupies very nearly 1 volume. On adding 0·5 volume of oxygen gas, a new combustion takes place, and the whole gaseous matter disappears. It would seem that, by the first combustion, the whole phosphorus is consumed, leaving the hydrogen very nearly pure. It is obvious, that half a volume of the oxygen gas was employed in converting the hydrogen of the gas into water. The remaining 0·75 volume of oxygen converted the phosphorus vapour into phosphoric acid; but phosphorus requires its own volume of oxygen gas for this purpose. From this it is evident that the altered gas is a compound of

1 volume hydrogen gas . .	0·0694
0·75 volume phosphorus vapour .	0·6250
	0·6944

Hence it contains just nine times as much phosphorus as hydrogen, and its specific gravity is

0·6944, or ten times that of hydrogen; and its atomic weight is 1·25. We may distinguish this altered gas by the name of *sub-phosphuretted hydrogen.*

Bihydroguret of phosphorus.

(2.) Bihydroguret of phosphorus was obtained by Davy, by heating crystallized phosphorous acid. When sulphur is heated in it, the volume of the gas is just doubled, and it is converted into sulphuretted hydrogen gas. Now, it will be shown in the next section, that sulphuretted hydrogen gas contains just its own volume of hydrogen gas. Hence it is obvious, that bihydroguret of phosphorus contains twice its volume of hydrogen gas.

This gas has a similar smell to phosphuretted hydrogen gas. It does not burn spontaneously when mixed with common air, or hydrogen gas; but combustion takes place readily, if an electric spark be passed through the mixture. For complete combustion, 1 volume of it must be mixed with 1·5, or with 2 volumes of oxygen gas. The gases disappear; and, with the smaller proportion of oxygen gas, we obtain phosphorous acid, with the greater phosphoric acid. From these facts it is obvious that the gas is a compound of

2 volumes hydrogen gas
1 volume phosphorus vapour } condensed into one volume.

Its specific gravity, therefore, must be the sum of twice the specific gravity of hydrogen

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gas and the specific gravity of phosphorus vapour added together, or 0·9722. For,

Twice sp. gr. of hydrogen gas	= 0·1388
Sp. gr. of phosphorus vapour	= 0·8333
	0·9722 = sp. gr. of the gas.

Bihydroguret of phosphorus is the fourth gas which we have met with, possessed of this specific gravity. The other three are azotic gas, carbonic oxide, and olefiant gas.

Thus it appears, that the composition and atomic weights of the various compounds of phosphorus with oxygen and hydrogen are as follows:

	PHOSPHORUS.	OXYGEN.	ATOMIC WEIGHT
1. Phosphorous acid .	1 atom	+ 1 atom	2·5
2. Phosphoric acid .	1	+ 2	3·5
		HYDROGEN.	
3. Phosphuretted hydr.	1	+ 1 atom	1·625
4. Bihydroguret of phosph.	1	+ 2	1·75
5. Subphosphuretted hydr.	0·75	+ 1	1·25

Bihydroguret of phosphorus has both the specific gravity and atomic weight of azotic gas.

SECT. V.

OF THE ATOMIC WEIGHT OF SULPHUR.

Sulphur forms three acid compounds with oxygen, distinguished by the names of *hyposul-*

phurous acid, *sulphurous acid*, and *sulphuric acid*. Let us, in the first place, determine the atomic weight of sulphuric acid, which is the most important of these compounds.

Atomic weight of sulphuric acid.

I. 1. Sulphate of potash is a salt which usually crystallizes in pyramidal dodecahedrons, though its primary form is an oblique four sided prism; and it contains no water of crystallization. 11 grains of sulphate of potash, and 13·25 grains of chloride of barium, were dissolved in separate portions of distilled water: the two solutions being mixed, a double decomposition took place; and sulphate of barytes, being insoluble, immediately precipitated to the bottom. The residual liquid, which was transparent and colourless, was tested with sulphate of soda, and with muriate of barytes; but by neither of these reagents was it in the least affected—showing that it contained no sensible quantity either of barytes or sulphuric acid.

From this experiment it follows, that the sulphuric acid in 11 grains of sulphate of potash just saturates the barytes from 13·25 grains of chloride of barium; but the barytes from that quantity of chloride is just 9·75 grains, which is equivalent to the atomic weight of barytes. When the sulphate of barytes formed in the preceding experiment was washed, dried, and exposed to a red heat, its weight was exactly 14·75 grains; and of this weight, 9·75 grains

were barytes. Hence sulphate of barytes is composed of

Barytes . .	9·75
Sulphuric acid .	5
	14·75

The salt being neutral, and 9·75 representing an atom of barytes, 5 must represent the atomic weight of sulphuric acid.

The potash in 11 grains of sulphate of potash must weigh 6, which is equivalent to an atom; for it just saturates 4·625 grains of muriatic acid, which is equivalent to an atom; and we have seen that the sulphuric acid in it weighs 5. Consequently, sulphate of potash is a compound of

Sulphuric acid .	5 = 1 atom.
Potash . .	6 = 1 atom.
	11

Method of manufacturing it.

2. Sulphuric acid is manufactured in this country, by the combustion of sulphur, which converts it into sulphurous acid gas. This gas passes into large leaden chambers, the bottom of which is covered with about 6 inches of water; together with the sulphurous acid gas, a quantity of the vapour of nitrous acid passes into the leaden chamber. These two acids have the property of uniting together; and they form minute

crystals, which fall into the water at the bottom of the chamber. The moment they come in contact with that liquid, a decomposition takes place;—the sulphurous acid is converted into sulphuric acid, and the nitrous acid into deutoxide of azote. This last substance makes its escape in the gaseous state; but immediately comes in contact with the common air of the chamber, and is converted into nitrous acid, which, uniting with a new dose of sulphurous acid, falls again into the water. These decompositions and new formations continually go on as long as the air of the chamber contains oxygen gas and sulphurous acid. The water, when sufficiently impregnated with sulphuric acid, is drawn off from the bottom of the chamber, and concentrated as far as possible in leaden boilers. It is then put into glass or platinum retorts, and kept in a heat of at least 600°, till as much concentrated as possible.*

Composition of the acid of commerce.

Acid, thus prepared, is a clear, transparent, colourless liquid like water, with a certain degree of consistency, so as to adhere to the sides of a

* The acidulous water, when taken out of the leaden chambers, has a specific gravity of about 1·22. It is a compound of about 1 atom sulphuric acid, and 15 atoms water. It is concentrated in the leaden boilers till its specific gravity becomes 1·75. In this state it is nearly a compound of 1 atom acid, and 2 atoms water; the boiling point of acid of this strength is 435°. Beyond this strength it cannot be conveniently carried in leaden vessels, because its corroding action on the lead increases at a great rate as the boiling point rises.

phial like oil. When quite free from all impurity, its specific gravity (when as strong as possible) is 1·847:—if it be heavier than this, it is contaminated with lead. The liquid, in this state, is a compound of 1 atom acid and 1 atom water. Now

1 atom acid = 5
1 atom water = 1·125

6·125

So that 6·125 parts of it contain 1·125 water and 5 of pure acid. Acid of this strength requires the highest temperature to boil it. Mr. Dalton states that its boiling temperature is 620°—but it is extremely difficult to determine such high temperatures with accuracy. I have satisfied myself, however, that the boiling point of this acid is above 600°.

If to 6·125 parts of this acid we add 1·125 parts of water, so as to form a compound of 1 atom acid and 2 atoms water, we obtain a liquid of the specific gravity of 1·78. Acid of this strength possesses the remarkable property of freezing at a higher temperature than acid of any other strength—its freezing point, according to the experiments of Mr. Keir, being 45°. Its boiling point, according to Mr. Dalton, is 435°.

3. Protosulphate of iron is a salt composed of

Formation of fuming acid.

1 atom sulphuric acid	= 5
1 atom protoxide of iron	= 4·5
7 atoms water	= 7·875
	17·375

So that an integrant particle of it weighs 17·375, and 4 integrant particles weigh 69·5 parts. If we expose 69·5 parts of this salt to a sufficient heat, it becomes white and loses 30·375 parts of water. Now, the whole water contained in 69·5 parts of this salt is obviously 31·5 parts; consequently, there still remains 1·125 parts of water united to the salt; and the salt thus heated is a compound of

4 atoms sulphuric acid	= 20
4 atoms protoxide of iron	= 18
1 atom water	= 1·125
	39·125

When these 39·125 parts are put into an earthenware retort, and exposed to a strong heat, one half of the sulphuric acid, amounting to 10 parts, is decomposed into 8 parts of sulphurous acid, which flies off and is dissipated, and 2 parts of oxygen, which, uniting to the 18 parts of protoxide of iron, convert them into 20 parts of peroxide of iron. The remaining 10 parts of the sulphuric acid pass over into the receiver united to the 1·125 of water.

This is the process followed at Nordhausen in

Germany, by which the fuming sulphuric acid, which answers so well for dissolving indigo, is obtained. Its colour is always dark, and it is opaque. I do not know the reason of this opacity, but suspect the presence of some selenium in it, from some phenomena which I have observed. The specific gravity of this acid is 1·896. I find it, by a careful analysis, to be a compound of 2 atoms acid, and 1 atom water. Now

2 atoms acid	= 10
1 atom water	= 1·125
	11·125

So that an integrant particle of it weighs 11·125, and contains 1·125 parts water and 10 parts of pure acid.

4. When this acid is exposed to the air, it smokes, in consequence of its great avidity for moisture. It is much more volatile than the sulphuric acid of this country. When heated in a glass retort to which a receiver is luted, and surrounded with a mixture of snow and salt, one half of the acid passes over in a solid state, forming a snow white solid acid, like asbestus in appearance. What remains in the retort is a compound of 1 atom acid and 1 atom water—or it is precisely similar to the acid of this country. I have not been able to determine the specific gravity of this acid: its avidity for water is so great

Pure dry sulphuric acid.

that it smokes violently when exposed to the air, and is dissipated so speedily that it cannot be weighed. But, by dropping a piece of it into a known weight of water, and then determining the increase of the weight of the liquid, I was enabled (by throwing down the acid by means of muriate of barytes) to show that, when solid, it consists of pure acid, totally destitute of water. I have obtained it crystallized in flat rhomboids, quite transparent, the large faces deviating only a few degrees from 90°.

It is converted into vapour at a temperature which must be low, though I have not determined it with accuracy. The specific gravity of this vapour is 2·7777, that of common air being unity. One volume of it is capable of uniting with, and condensing, just 2 volumes of ammoniacal gas. A volume, therefore, is equivalent to an atom of the acid, for 2 volumes of ammoniacal gas are just equivalent to 1 atom of ammonia.

II. Let us now determine the atomic weight of *sulphurous acid.*

Composition of sulphurous acid.

1. This acid contains less oxygen than sulphuric; for when the alkaline sulphites are dissolved in water, they are gradually changed into sulphates, while at the same time a quantity of oxygen gas is absorbed. Its atomic weight, then, is less than that of sulphuric acid.

2. Sulphurous acid is a gaseous compound,

which may be easily formed by burning sulphur in oxygen gas. Now, when we convert oxygen gas into sulphurous acid by this process, we do not produce any alteration in its volume, but we produce an increase in its specific gravity. Hence, it is obvious that, if from the specific gravity of sulphurous acid gas we subtract the specific gravity of oxygen gas, the remainder will give us the weight of sulphur united to a volume of oxygen gas. I have shown in a paper on the Specific Gravity of the Gases, inserted in the 16th volume of the Annals of Philosophy, (p. 256) that the true specific gravity of sulphurous acid is $2{\cdot}222\dot{2}$; and we have seen that oxygen gas weighs $1{\cdot}111\dot{1}$. Hence, it is obvious that sulphurous acid is composed of

Sulphur	$1{\cdot}111\dot{1}$
Oxygen	$1{\cdot}111\dot{1}$
	$2{\cdot}222\dot{2}$

Or of equal weights of each constituent. We may consider sulphurous acid gas as a compound of

1 volume oxygen gas
1 volume sulphur vapour } condensed into 1 volume.

3. Sulphuretted hydrogen gas may be obtained by mixing together sulphuret of antimony and muriatic acid in a small retort, and applying the heat of a lamp. The gas may be collected over

Composition of sulphuretted hydrogen.

mercury. This gas has a fetid odour, and a specific gravity of 1·1805 : it burns with a blue flame; and 1 volume of it, for complete combustion, requires 1½ volume of oxygen gas. Water is formed, and a quantity of sulphurous acid gas, just equal to the volume of sulphuretted hydrogen gas, consumed.

This combustion is sufficient to enable us to determine the composition of sulphuretted hydrogen gas. It may be proper to mention, in the first place, that when sulphur is heated in hydrogen gas, the gas is partly converted into sulphuretted hydrogen; but no alteration whatever takes place in its volume. From this it is evident, that a volume of sulphuretted hydrogen gas contains just a volume of hydrogen gas.

This being understood, let us proceed to analyze the composition of this gas from its combustion with oxygen. One volume of it requires 1½ volume of oxygen gas, and forms water and a volume of sulphurous acid gas. The half volume of oxygen gas went to the formation of water and united with a volume of hydrogen gas: the whole volume of oxygen must have gone to the formation of sulphurous acid, and it must have combined with a volume of sulphur vapour.

Thus, we see that sulphuretted hydrogen gas is a compound of

1 volume hydrogen gas
1 volume sulphur vapour } condensed into 1 volume.

And we obtain its composition by stating the specific gravity of each constituent, for it must be a compound of

Hydrogen	0·0694	or	0·125
Sulphur	1·1111	-	2·000
	1·1805		2·125

No doubt, it consists of an atom of hydrogen united to an atom of sulphur;—0·125 is the weight of an atom of hydrogen, and 2 must, therefore, represent the atomic weight of sulphur. Atom of sulphur.

3. We see from the composition of sulphuretted hydrogen gas, that a volume of sulphur vapour is equivalent to an atom, and a volume of oxygen gas is equivalent to 2 atoms. Now, sulphurous acid gas is a compound of 1 volume sulphur vapour and 1 volume oxygen gas;—it is, therefore, a compound of 1 atom sulphur and 2 atoms oxygen. And, since an atom of sulphur weighs 2, the atomic weight of sulphurous acid is 4. Atomic weight of sulphurous acid.

III. It would be easy to show, by a similar process of reasoning, that an atom of hyposulphurous acid weighs 3.

Thus, the atomic weights of sulphur and its acid compounds are as follows:

	WEIGHT OF ATOM.
Sulphur	2

Hyposulphurous acid .	3
Sulphurous acid . .	4
Sulphuric acid . .	5
Sulphuretted hydrogen .	2·125

	SULPHUR.	OXYGEN.
Hyposulphurous acid is a compound of	1 atom	+ 1 atom
Sulphurous	1	+ 2
Sulphuric	1	+ 3
		HYDROGEN.
Sulphuretted hydrogen . .	1	+ 1

The hyposulphuric acid of Gay-Lussac is formed by the union of an integrant particle of sulphurous and sulphuric acids with each other; consequently, its atomic weight is 9; and it is a compound of 2 atoms sulphur with 5 atoms oxygen.

SECT. VI.

OF THE ATOMIC WEIGHT OF SELENIUM.

Selenium is so difficult to procure, that I have been obliged to confine my experiments to very minute quantities; not having had more in my possession than about 40 grains, which did not put it in my power to obtain satisfactory results. For the investigation of its atomic weight, therefore, I must rely almost entirely upon the experiments of Berzelius. Fortunately, his experi-

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ments in general are made with so much precision that they furnish very good approximations.

Selenium forms with oxygen an acid, which has been distinguished by the name of *selenic acid*, and with hydrogen a gaseous compound, which has been called *selenietted hydrogen gas*.

1. Selenic acid combines with most bases in two proportions, and with a considerable number in three proportions, forming with them, salts distinguished by the names of *seleniates*, *biseleniates*, and *quadroseleniates*. Two seleniates have been analyzed by Berzelius: namely, *seleniate of soda*, and *seleniate of barytes*. Let us deduce from each of these analyses, the atomic weight of selenic acid.

Analysis of seleniate of soda;

(1.) Seleniate of soda does not crystallize readily, though it may be made to deposite crystalline grains. The biseleniate crystallizes more easily, and assumes the form of needles. Berzelius rendered a given weight of each of these salts anhydrous, mixed each with twice its weight of sal-ammoniac, and applied a subliming heat; the selenic acid was sublimed and decomposed, and nothing remained but the base of each salt united to muriatic acid, or rather, in the state of chloride of sodium. 100 parts of seleniate of soda furnished $66\frac{2}{3}$ parts of common salt, equivalent to 35·55 soda. Hence, this salt is composed of

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Selenic acid	64·44	or	7·25
Soda	35·55	--	4
	100		

100 parts of biseleniate (anhydrous, but deprived also of a little of the acid) when treated in the same way, yielded 41⅔ parts of common salt, equivalent to 22·22 parts of soda.* Hence, the constituents of the salt are

Selenic acid	77·77	or	14
Soda	22·22	-	4
	100		18

It is obvious that the first of these two salts contains one atom, and the second two atoms of selenic acid, united to an atom of soda. But the atomic weight of selenic acid resulting from the two analyses does not quite agree; according to the first analysis it is 7·25; according to the second 7.

And seleniate of barytes.

(2.) Seleniate of barytes is insoluble in water, and can only be obtained in the state of a white powder. But biseleniate of barytes is soluble, and probably contains water of crystallization.

Two parts of anhydrous seleniate of barytes dissolved in muriatic acid, and precipitated by sulphuric acid, furnished 1·765 parts of sulphate of barytes equivalent to 1·1657 parts barytes. Hence, the salt is composed of

* Ann. de Chim. et de Phys. IX. 258.

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Selenic acid	0·8343	or	6·9782
Barytes	1·1657	-	9·75
	2·0000		

1271 parts of anhydrous biseleniate of barytes treated in the same way, yielded 785 parts of sulphate of barytes, equivalent to 518·9 parts of barytes. Hence, biseleniate is composed of

Selenic acid	752·1	or	14·132
Barytes	518·9	-	9·75
	1271·0 *		

According to the result of the analysis of seleniate of barytes, the atomic weight of selenic acid is 6·9782; according to the analysis of the biseleniate, it is 7·066.

Though these results do not accurately correspond with each other, they, upon the whole, concur in rendering it very probable that the true atomic weight of selenic acid is 7. I consider the analysis of seleniate of barytes as susceptible of greater precision than that of the analysis of seleniate of soda. Now, the atomic weight of selenic acid, deduced from the mean of the analysis of seleniate and biseleniate of barytes, is 7·02211, which comes extremely near to 7.

Attempts to determine the atom of selenic acid.

2. I may state here a few attempts which I made to determine the atomic weight of selenic

* Ann. de Chim. et de Phys. IX. 262.

acid, though they were not attended with the success which I had anticipated. 21·63 grains of crystallized selenic acid heated till they began to sublime, and therefore considered as anhydrous, were dissolved in water, and crystallized carbonate of soda in powder was added by small quantities at a time, till the liquid began to give a violet colour to cudbear paper. 43·43 grains of the carbonate were necessary to produce this effect. The liquid was now evaporated to dryness, and the dry residuum exposed to a temperature of about 600° on the sand bath, till it ceased to give out moisture. It weighed 30·4 grains. As it contained an excess of soda, the salt was again dissolved in water, and a few drops of muriatic acid being added, the whole was again evaporated to dryness. It now weighed 32⅔ grains, and, consequently, had increased in weight 2·266 grains.

This increase of weight was occasioned by the union of the muriatic acid with the surplus soda. No effervescence could be perceived, so that I had no evidence that any carbonic acid had been driven off. The salt having been exposed to heat, it is obvious, that the common salt was converted into chloride of sodium. The simplest way of determining its quantity, will be to consider it a compound of 3·5 muriatic acid and 4 soda. Now, 3·5 : 4 : : 2·266 (the augmentation of weight) : 2·59 = soda in the common salt. The common

salt then amounted to 4·856 grains; this subtracted from 32·666 leaves 27·816 grains of biseleniate of soda. Now, it contains 21·63 grains of selenic acid. Hence, biseleniate of soda is composed of

Selenic acid	21·63	or	14
Soda	6·18	-	4
	27·61		

This experiment gave therefore 7 for the atomic weight of selenic acid. But I consider this as merely an accidental circumstance, because, on repeating it a second time, the biseleniate was found a compound of

Selenic acid	12·353
Soda	4

This would reduce the atomic weight of selenic acid to 6·176. But this mode of experimenting is not susceptible of the requisite degree of precision for deciding so delicate a point. Every time the salt was evaporated to dryness, a little selenium was separated, which prevented the quantity of salt from remaining quite permanent.

I attempted to determine the atomic weight of selenic acid, by precipitating it from seleniate of soda, by means of muriate of barytes. But the precipitation produced by this salt is only partial—a portion of selenic acid remaining in solution even after a considerable excess of muriate of barytes had been added.

Foiled in all these attempts, it would have been requisite in order to determine the atomic weight of this acid, to have had recourse to the direct analysis of some of the seleniates. But, besides that my stock of acid was exhausted, I had no reason to expect more accurate results from such an analysis, than those already obtained by Berzelius.

Upon the whole, I have little hesitation in fixing upon 7 as the true atomic weight of this acid.

Composition of selenietted hydrogen.

2. The experiments made by Berzelius on selenietted hydrogen gas, will enable us easily to determine the atomic weight of selenium, from which the composition of selenic acid may be directly deduced.

This gas is colourless, has a smell somewhat similar to that of sulphuretted hydrogen gas, is very soluble in water, reddens vegetable blues, and precipitates metals from their solutions. To ascertain its constituents, Berzelius passed a current of it through a solution of acetate of silver; seleniet of silver was precipitated, which weighed when dry 1·888 parts. This seleniet he dissolved in nitric acid, and threw the solution, while boiling hot, into muriatic acid. By this contrivance, the seleniet was decomposed, and the silver thrown down in the state of chloride of silver. The chloride thus obtained, weighed 1·844. Now, chloride of silver is a

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compound of 1 atom chlorine = 4·5, and 1 atom silver = 13·75;—so that 18·25 grains of it contain 13·75 grains of silver: consequently, 1·844 parts of this chloride must consist of

Chlorine	0·4546
Silver	1·3894
	1·8440

Now, this 1·3894 of silver constituted one of the constituents of the 1·888 parts of seleniet of silver;—the only other constituent was the selenium: consequently, seleniet of silver is composed of

Silver	1·3894	or	13·75
Selenium	0·4986	-	4·9343
	1·8880		

13·75 being the atomic weight of silver, 4·9343 must represent the atomic weight of selenium.

The silver in the acetate, through which the selenietted hydrogen gas was passed, was in the state of an oxide composed of

1 atom silver	= 13·75
1 atom oxygen	= 1
	14·75

But in the seleniet it was in the metallic state: the reason was, that the selenietted hydrogen and the oxide of silver, had mutually decom-

posed each other. The hydrogen of the gas had united to the oxygen of the oxide, and formed water—while the selenium and the silver combining together, formed the seleniet of that metal. Seleniet of silver being a compound of 1 atom silver and 1 atom selenium, and water of 1 atom oxygen and 1 atom hydrogen, it is evident, that selenietted hydrogen must be a compound of 1 atom hydrogen and 1 atom selenium. Its constituents, then, from the preceding analysis, must be

Selenium	4·9343
Hydrogen	0·125

But if 7 be the atomic weight of selenic acid, it is obvious that the atomic weight of selenium must, in fact, be 5 instead of 4·9343; for selenic acid must be a compound of

1 atom selenium
2 atoms oxygen:

And its weight could not be 7, unless the weight of selenium were 5.

The true composition of selenietted hydrogen, then, must be

Selenium	5	or	40
Hydrogen	0·125	-	1
	5·125		

And the atomic weight of this gas must be 5·125.

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It will be shown in the next chapter, that the specific gravity of most of the gases is obtained by multiplying their atomic weights by 0·5555, or half the specific gravity of oxygen gas. Now, $5{\cdot}125 \times 0{\cdot}5555 = 2{\cdot}8522$, which must be the specific gravity of selenietted hydrogen gas.

SECT. VII.

OF THE ATOMIC WEIGHT OF ARSENIC.

Arsenic has the property of combining with, at least, two proportions of oxygen, and of forming two well known and very poisonous compounds, distinguished by the names of *arsenious* and *arsenic acids*. It unites, likewise, with hydrogen gas, and forms a gaseous compound, the properties of which have been but imperfectly investigated. An examination of the acids of arsenic will enable us to determine the true atomic weight of this substance.

Atomic weight of arsenic acid.

1. Arsenic acid is easily obtained, by dissolving white arsenic in nitric acid, mixed with a small quantity of muriatic acid, and evaporating the solution to dryness. It is a white matter, soluble in water; and the aqueous solution has a very sour taste. With most of the metallic oxides it forms compounds, insoluble in water; but easily soluble in nitric acid;—with ammonia,

potash, and soda, it unites in two proportions, and forms soluble compounds with each. Binarseniates of potash and soda crystallize readily —the former in four sided prisms—the latter in rhomboids. Binarseniate of soda contains rather more than 20 per cent. of water, being composed of

2 atoms arsenic acid	=	15·5
1 atom soda .	=	4·0
5 atoms water .	=	5·625
		25·125

as I ascertained by a careful analysis.* When this salt is heated to about 500°, it loses the whole of its water of crystallization, melting at first into a liquid, and then falling down in the state of a white powder. At a red heat this powder melts into a transparent liquid, which is quite anhydrous.

If we add 18 grains of crystallized carbonate of soda to a solution of 25·125 grains of crystals of binarseniate of soda, and agitate the mixture till the whole soda be dissolved, and till the carbonic acid has made its escape, the liquid will be found incapable of reddening vegetable blues. Now, 18 grains of carbonate of soda contain just 4 grains of soda, which is equivalent to an atom.

* Or rather synthesis. The experiment, which is of importance, because it proves the inaccuracy of Berzelius's opinions respecting the composition of this acid, will be given at large in chapter XVIII. of this work.

It is evident, from this, that the rhomboidal crystals contain two atoms of arsenic acid united to 1 atom of soda; for 25·125 grains of them contain just 4 grains of soda, which is equivalent to an atom.

It has been already explained, that nitrate of lead is an anhydrous salt composed of

1 atom nitric acid	=	6·75
1 atom protoxide of lead	=	14
		20·75

Consequently, 41·5 grains contain 28 grains of protoxide of lead, which is equivalent to 2 atoms.

19·5 grains of anhydrous binarseniate of soda, and 41·5 grains of crystallized nitrate of lead, were dissolved in separate portions of distilled water. The solutions being mixed, a double decomposition took place; the arsenic acid and protoxide of lead united together, and precipitated in the state of an insoluble arseniate. The clear transparent colourless liquid remaining, after this salt had subsided, reddened vegetable blues; but it was exactly neutralized by the addition of 18 grains of crystallized carbonate of soda. The liquid thus neutralized was tested by sulphate of soda, and likewise by nitrate of lead; but the solutions of neither of these salts produced any sensible alteration; showing the absence both of lead and arsenic acid.

Now, it is evident from this experiment, that 19·5 grains of anhydrous binarseniate of soda contain exactly 4 grains of soda;—for the 13·5 grains of nitric acid in 41·5 grains of nitrate of lead require 8 grains of soda to neutralize them. To accomplish this neutralization, (after the oxide of lead had been separated) it was necessary to add only 18 grains of carbonate, containing 4 grains of soda; consequently, 4 grains had been already combined with it, and these 4 grains could only have been derived from the binarseniate of soda. 19·5 grains of anhydrous binarseniate of soda, then, are composed of

Arsenic acid	15·5
Soda	4·0
	19·5

These 15·5 grains of arsenic acid neutralized 28 grains of protoxide of lead, which are equivalent to 2 atoms; consequently, 15·5 grains of arsenic acid must be equivalent to 2 atoms. Thus, we see that the atomic weight of arsenic acid is 7·75.

Composition of arsenic acid.

2. Let us now investigate the constitution of this acid.—Into a small green glass retort, previously weighed and the weight marked upon it with a diamond, 4·75 grains of clean metallic arsenic were introduced, and about an ounce of rather strong nitric acid was poured over it. A moderate heat being applied, the arsenic dissolved with

efferverscence. As soon as the solution was completed, a receiver was attached to the retort, the whole nitric acid was not only distilled off, but the heat was continued till the inside of the retort had become quite dry. By this process, the arsenic had been converted into arsenic acid, and its weight was exactly 7·75 grains.

From this experiment it is obvious, that arsenic acid is a compound of

Arsenic	4·75
Oxygen	3
	7·75

From this it appears, that the atomic weight of arsenic is 4·75, and that arsenic acid is a compound of 1 atom arsenic and 3 atoms oxygen. Atomic weight of arsenic.

3. Let us now investigate the atomic weight of arsenious acid.—This is the substance known, in common language, by the name of *white arsenic*. It reddens vegetable blues, dissolves in water, and unites to bases; though it does not seem capable of neutralizing them. But the atomic weight, and the composition of this acid, is rendered evident by the following simple and easy experiment. Atomic weight of arsenious acid.

6·75 grains of pure arsenious acid were put into a small retort, the weight of which had been previously determined; and there was poured over it, about an ounce of a mixture of

12 parts nitric acid of the specific gravity 1·25, and 1 part of muriatic acid of the specific gravity 1·2. The retort being exposed to a moderate heat, the arsenious acid was soon dissolved with effervescence; but the heat was continued till all the liquid portion was distilled over into the receiver, and till the interior surface of the retort had become quite dry. The best way of drying the retort is to put it on the sand bath, and to cover the whole of it except the extremity of the beak, with sand of a temperature between 500° and 600°, and keep it in this situation for several hours. By this process the arsenious acid was converted into arsenic acid, and its weight was found to be exactly 7·75 grains.

From this experiment it is evident, that arsenious acid contains one atom of oxygen less than arsenic acid. Consequently, its atomic weight is 6·75; and it is a compound of one atom arsenic, and two atoms oxygen.

From the preceding investigation it is obvious, that an atom of arsenic weighs 4·75, and that the constitution and atomic weights of the acids of arsenic are as follows:

	ARSENIC.		OXYGEN.	ATOMIC WEIGHT.
Arsenious acid of	1 atom	+	2 atoms	6·75
Arsenic acid - -	1	+	3	7·75

So that the constitution of these acids is the same as that of sulphurous and sulphuric acids.

4. It is exceedingly probable that there exists

an oxide of arsenic, composed of one atom arsenic and one atom oxygen, and, consequently, weighing 5·75. When very thin crusts of metallic arsenic are exposed to the air, they soon lose their metallic lustre, and crumble into a black powder. This black powder is probably the oxide in question; but it has not been particularly examined by modern chemists. When I was occupied with the experiments related in this section, I made some attempts to investigate its composition, but they were not successful, and I have not again had leisure to resume them.

Arsenietted hydrogen.

5. Arsenic has the property, likewise, of combining with hydrogen gas, and of forming a gaseous compound, which was first discovered by Scheele, but has never yet been obtained in a state of purity. From our knowledge of the constitution of the other compounds of the combustible substances with hydrogen gas, however, there can be no difficulty in stating its leading properties from theory.

It is probably a compound of one atom arsenic and one atom hydrogen, and, consequently, its atomic weight must be 4·875.

From the analogy of the other gaseous compounds of hydrogen and a combustible, there seems little doubt that it is a compound of

1 volume arsenic vapour
1 volume hydrogen gas } condensed into 1 volume.

We will obtain its specific gravity in the gaseous

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state by multiplying its atomic weight by 0·5555̇. Now, 4·875 × 0·5555̇ = 2·7083̇ = specific gravity of arsenietted hydrogen gas.

The specific gravity of arsenic vapour ought to be 2·6388̇.

One volume of arsenietted hydrogen gas will require for complete combustion, either 1·5 volume, or two volumes of oxygen gas. In the first case, water and arsenious acid, and in the second case, water and arsenic acid will be formed.

SECT. VIII.

OF THE ATOMIC WEIGHT OF TELLURIUM.

THE atomic weights of all the acidifiable combustibles have now been investigated, except of tellurium, which is so scarce a substance, that I have never had it in my power to make any experiments upon it. But Berzelius has determined the composition of its oxide with his usual accuracy. We may therefore take advantage of his experiments to complete the series of the atomic weights of all the simple acidifiable combustibles.

According to Berzelius, tellurium unites with only one dose of oxygen, and forms an oxide which has the curious property of forming neutral salts, both with oxides and acids—so that

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it possesses at once the characters of an acid and an alkali. Davy discovered that it forms a gas with hydrogen, similar in its properties to sulphuretted, phosphuretted, selenietted, and arsenietted hydrogen gases. But no experiments have been made to determine the specific gravity or composition of this gas.

1. Berzelius made two analytical experiments, from which the atomic weight of tellurium may be deduced.

Composition of oxide of tellurium.

(1.) He found that 100 parts of tellurium became 124·8 parts of oxide; hence, oxide of tellurium is a compound of

Tellurium	100	or	4·032
Oxygen	24·8	-	1

We see that the oxide of tellurium is a compound of one atom tellurium, and one atom oxygen. The atomic weight of tellurium by this experiment is 4·032, or rather less than one per cent. more than 4. Now, it is exceedingly difficult to make an experiment similar to the one by which Berzelius determined the composition of oxide of tellurium, without some loss. If the loss amounted to 0·2, which is no more than $\frac{1}{833}$th part of the whole, then the oxide of tellurium is composed as follows:

Tellurium	100	or	4
Oxygen	25	-	1

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And the atomic weight of tellurium will be exactly 4, and that of the oxide 5.

Bitellurate of lead.

(2.) Berzelius found that 201·5 parts of fused tellurate of lead contained just the same weight of protoxide of lead, which 157 parts of sulphate of lead do.* But 157 parts of sulphate of lead contain 115·684 parts of protoxide of lead; hence, it follows, that tellurate of lead is composed of

Protoxide of lead	115·684	or	14
Oxide of tellurium	85·816	-	10·385
	201·500		

To reconcile this experiment with the former, the salt analyzed must have been a bitellurate, or a compound of two atoms oxide of tellurium and one atom protoxide of lead.

The atomic weight of oxide of tellurium from the above analysis is 5·1925.

This is rather higher than the weight deduced from the composition of oxide of tellurium. The former experiment being much simpler, and consequently, susceptible of greater accuracy than the latter, there can be no hesitation in preferring it, and, consequently, in fixing upon 4 as the true atomic weight of tellurium, and 5 as the atomic weight of oxide of tellurium.

Telluretted hydrogen.

2. We may deduce the specific gravity and constitution of telluretted hydrogen gas, with a

* Annals of Philosophy, III. 250.

great deal of probability, from the known constitution of the other similar compounds. If it be a compound of

1 volume tellurium vapour
1 volume hydrogen gas } condensed into 1 volume,

as is the case with all the others, and if a volume of tellurium vapour be equivalent to an atom, then the atomic weight of telluretted hydrogen is 4·215, and its specific gravity 2·2916.

One volume of this gas will require, for complete combustion, one volume of oxygen gas, —one half of which will go to the formation of water, and the other, to the formation of oxide of tellurium.

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CHAP. VII.

OF THE RELATION BETWEEN THE ATOMIC WEIGHTS AND SPECIFIC GRAVITIES OF GASEOUS BODIES.

Gay-Lussac, in a paper published in the second volume of the *Memoires d'Arcueil*, demonstrated, a good many years ago, that when gases combine with each other, one volume of the one gas either combines with one volume, or two volumes, or three volumes of the other. Dr. Prout, in a paper inserted in the sixth volume of the *Annals of Philosophy*, first pointed out the connection which existed between the specific gravity and the atomic weights of the gases; and showed that, in general, the specific gravity is equal to the atomic weight multiplied by half the specific gravity of oxygen gas. I propose in this chapter to take a general view of the relation between the atomic weights and the specific gravities of all the known gases.

1. In the preceding chapters we have determined the atomic weights of all the simple bodies which are capable of assuming the gaseous form. Of these there are only four, which are gases in the uncombined state:—these are Oxygen,

Hydrogen, Chlorine, and Azote. There are seven simple bodies which are capable of combining with hydrogen, and forming with it a gaseous compound:—these are iodine, carbon, phosphorus, sulphur, selenium, arsenic, and tellurium. The two remaining bodies, boron and silicon, enter into gaseous combinations with fluoric acid,—a substance, the consideration of which is deferred till a future chapter; though the specific gravity and atomic weights of the gases will be inserted in the following tables, for the sake of completing the series of gaseous bodies.

Gases whose specific gravity = atom × ·555.

2. We have seen that water is a compound of one volume of oxygen gas, and two volumes of hydrogen gas; while, from the proportion in which hydrogen combines with all known bodies, there is every reason to consider two volumes of it as equivalent to an atom; or if we choose, for the sake of simplicity, to represent an atom of hydrogen by a volume of the gas, then we must represent an atom of oxygen by half a volume of the gas. We have seen that chlorine and azote have the same relation between their atomic weights and their volumes that hydrogen has; this is the case also with iodine, carbon, phosphorus, and sulphur, when in the state of vapour. The relation between the atomic weight and the volume of the vapours of selenium, arsenic, and tellurium, has not yet been determined by experiment; but there seems no reason

to hesitate about extending the same law to these bodies also.

Thus it appears, that the atomic weight of oxygen is obtained by dividing the specific gravity of oxygen gas by itself; for $\frac{1{\cdot}111}{1{\cdot}111} = 1$; but the atomic weights of the other gases and vapours are obtained by dividing the specific gravity of the gas or vapour by half the specific gravity of oxygen gas, or $0{\cdot}5\dot{5}5\dot{5}$.*

The specific gravities of oxygen gas, hydrogen gas, chlorine gas, and azotic gas, have been determined with rigid accuracy in the preceding chapters. The knowledge of the atomic weights of the other bodies will enable us to determine the specific gravities of the vapours and gases of which they constitute parts, with equal accuracy; for we obtain these specific gravities by multiplying the atomic weights by $0{\cdot}5\dot{5}5\dot{5}$.

The following table exhibits the atomic weights

* I need hardly point out to the reader, that the reason why the multiplicand of the specific gravity of the gases is $\frac{1}{2}$, or $\frac{1}{4}$th the specific gravity of oxygen gas, instead of simply $\frac{1}{2}$ and $\frac{1}{4}$th, is, that the specific gravities and the atomic weights are referred to different standards. The *specific gravity* of atmospheric air is reckoned unity, and that of every other gas is referred to it; but the atomic weight of oxygen being unity, and that of all the other gases referred to it, as far as atomic weights are concerned, it is obvious, that when specific gravities are to be converted into atomic weights, we must employ for our divisor half or $\frac{1}{4}$th the specific of oxygen gas, in order to change one system into the other. All this trouble would be saved, if we were to make the specific gravity of oxygen gas unity, as well as its atomic weight.

and specific gravities of all the gases and vapours coming under this law.

I. *Gases whose specific gravity is equal to the atomic weight multiplied by* 1·1111.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Oxygen gas . .	1	1·1111
Fluosilicic acid . .	3·25	3·6111

II. *Gases and vapours whose specific gravity = atomic weight multiplied by* 0·5555.

1. SIMPLE GASES AND VAPOURS.

Hydrogen gas . .	0·125	0·0694
Carbon vapour . .	0·75	0·4166
Phosphorus vapour .	1·5	0·8333
Azotic gas . . .	1·75	0·9722
Sulphur vapour . .	2	1·1111
Tellurium vapour . .	4	2·2222
Chlorine gas . .	4·5	2·5
Arsenic vapour . .	4·75	2·6388
Selenium vapour . .	5	2·7777
Iodine vapour . .	15·5	8·6111

2. HYDROGEN, COMBINED WITH A SIMPLE BASE.

Carburetted hydrogen .	1	0·5555
Phosphuretted hydrogen	1·625	0·9027
Subphosphuretted hydrogen	1·25	0·6944
Bihydroguret of phosphorus	1·75	0·9722
Sulphuretted hydrogen	2·125	1·1805
Telluretted hydrogen .	4·125	2·2916
Arsenietted hydrogen .	4·875	2·7083
Selenietted hydrogen .	5·125	2·8522

3. OXYGEN, COMBINED WITH A SIMPLE BASE.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Steam	1·125	0·625
Carbonic oxide gas	1·75	0·9722̇
Carbonic acid	2·75	1·5277̇
Protoxide of azote	2·75	1·5277̇
Nitric acid vapour	6·75	3·75
Sulphurous acid	4	2·2222̇
Sulphuric acid vapour	5	2·7777̇

4. OTHER COMPOUND GASES.

Cyanogen	3·25	1·8055̇
Fluoboric acid	4·25	2·3611̇
Sulphuret of carbon	4·75	2·6388̇
Chlorocarbonic acid	6·25	3·4722̇

The specific gravity of these 29 gases and vapours being obtained by multiplying the atomic weights of each by 0·5555̇, or half the specific gravity of oxygen, it is obvious, that in all of them a volume may be substituted for an atom; or, in other words, the specific gravities and atomic weights of all of them bear the same relation to each other. In oxygen gas and fluosilicic acid, on the contrary, an atom is represented by half a volume; so that, in the first set of gases, a volume contains twice as many atoms as in the second set.

3. There are five compound gases, whose atomic weights and specific gravities bear a different relation to each other from the gases in the pre-

Gases whose specific gravity = atom × 0·2777.

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ceding table. The compound gases in the preceding table may be considered as consisting of a volume, or a determinate number of volumes of each constituent, so condensed, that a volume of the compound gas bears the same relation to a volume of oxygen gas, as a volume of hydrogen gas does to a volume of oxygen gas; but there are four compound gases, which consist of a volume of each of the constituents united together, without any condensation whatever. Consequently, their specific gravities, instead of being equal to the specific gravities of all their constituents added together, are only the means of the specific gravities of the constituents. In reality, therefore, the volumes of these gases may be considered as doubled, with reference to their atomic weights. These gases are *deutoxide of azote*, *hydrocyanic acid vapour*, *muriatic acid*, and *hydriodic acid*.

(1.) Deutoxide of azote is composed of 1 volume of oxygen gas, and 1 volume of azotic gas, united together, without any alteration of volume; hence its specific gravity is the mean of the specific gravities of oxygen and azotic gases, or 1·0416̇.

(2.) Hydrocyanic acid, muriatic acid, and hydriodic acid, are composed respectively of one volume of hydrogen gas, united to a volume of cyanogen, chlorine, and iodine vapour, without any condensation.

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(3.) The constitution of ammoniacal gas is analagous to that of the four gases just mentioned. It is composed of 1 volume of azotic gas, and 3 volumes of hydrogen gas, condensed into two volumes; so that its specific gravity, instead of being equal to the specific gravity of azotic gas, added to thrice the specific gravity of hydrogen gas, is only half that quantity, or 0·59027. Therefore, with respect to its atomic weight, its bulk is also doubled.

From what has been just stated, it must be obvious, that in these five gases the specific gravity will be obtained by multiplying the atomic weight of each by 0·2777, or ¼th of the specific gravity of oxygen gas.

The following table exhibits the atomic weights and specific gravities of these gases:

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Ammoniacal gas .	2·125	0·59027
Hydrocyanic acid vapour	3·375	0·9375
Deutoxide of azote .	3·75	1·04166
35 Muriatic acid . .	4·625	1·28472
Hydriodic acid . .	15·625	4·34027

It is obvious that a volume of oxygen gas contains four times as many atoms as a volume of any of these five gases. When we compare these five gases with each other, an atom may be substituted for a volume; but when we compare them with the gases in the preceding table, two

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volumes represent an atom, while 1 volume of the second set of gases represents an atom. Thus, when we wish to combine 1 atom of sulphurous or carbonic acid with 1 atom of ammonia, we must mix 1 volume of the acid gas with 2 volumes of the ammoniacal gas.

Protoxide of chlorine.

4. The constitution of protoxide of chlorine is different from that of both the preceding sets of gases. It is composed (if Davy's experiments be accurate) of 4 volumes of chlorine, and 2 volumes of oxygen gas, condensed into 5 volumes. We obtain its specific gravity by adding together four times the specific gravity of chlorine gas, and twice the specific gravity of oxygen gas, and dividing the sum by five; this gives us 2·4444 for the specific gravity of this gas. As it is a compound of 1 atom chlorine and 1 atom oxygen, its atomic weight is obviously 5·5. Now, the specific gravity of this gas is obtained by multiplying its atomic weight by 0·4444, which is $\frac{8}{9}$ths of the specific gravity of oxygen gas; for $5{\cdot}5 \times 0{\cdot}4444 = 2{\cdot}4444$. The reason of this is obvious from the peculiar condensation which the constituents of this gas undergo when they combine.

Olefiant gas.

5. Olefiant gas has not been inserted in the preceding tables; it has been reserved for separate notice, on account of the peculiarity of its nature. Its specific gravity is 0·9722; and it is obvious, from the phenomena of its combustion,

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that it consists of 2 volumes of hydrogen gas, and 2 volumes of carbon vapour, condensed into one volume. Now, as in these two bodies atoms may be substituted for volumes, this gas is obviously a compound of 2 atoms hydrogen, and 2 atoms carbon. Hence its atomic weight is 1·75; but $1{\cdot}75 \times 0{\cdot}5555 = 0{\cdot}9722$;—so that this gas coincides with the compound gases in the second table; and it might have been inserted in the second division of that table, after carburetted hydrogen.

But the singularity of this substance, which is obviously a compound of 1 atom hydrogen and 1 atom carbon, is, that it seems capable of forming a variety of gases, differing from each other in the number of integrant particles of carburet of hydrogen, which a single volume contains. Gases seem to exist, containing 1 integrant particle, 2 integrant particles, 3 integrant particles, 4 integrant particles, and 6 integrant particles. Of course, the specific gravity of each of these gases will be different, though each is regulated by the law which determines the specific gravities of the compound gases in the second table. It may be worth while to exhibit the atomic weights and specific gravities of these gases.

	ATOMIC WEIGHT.	SP. GRAVITY.
Simple hydrocarburet . .	0·875	0·4861
Olefiant gas	1·75	0·9722
Oil gas, or tritohydrocarburet	2·625	1·4583

	ATOMIC WEIGHT.	SP. GRAVITY.
Sulphuric ether vapour, containing 4 volumes	3·5	1·9444
Naphtha vapour, containing 6 vols.	5·25	2·9166

The only one of these five gases not yet detected is the first. But it may be looked for among the inflammable gases produced from vegetable bodies, or from pit coal.

CHAP. VIII.

OF THE ATOMIC WEIGHTS OF THE FIXED ALKALIES AND ALKALINE EARTHS.

The atomic weights of the simple bodies which constitute the bases of the acids, have been determined in the preceding chapters. I propose in the five following chapters to investigate the atomic weights of the bases of the alkaline bodies, including under the term *alkali*, all bases which are capable of neutralizing acids.

The substances usually distinguished by the name of *fixed alkalies* and *alkaline earths*, are

1 Potash	4 Barytes	7 Magnesia
2 Soda	5 Strontian	
3 Lithia	6 Lime	

Sir H. Davy first showed that these bodies are compounds of oxygen, with certain white coloured solid metals, which have so strong an affinity for oxygen that they can with difficulty be preserved in the metallic state. Indeed, if we except potassium and sodium, the remainder, as far as utility is concerned, may be considered as still unknown; for they cannot be procured in such quantities as to be susceptible of useful applications. The fixed alkalies and alkaline

earths, on the contrary, which constitute the *oxides* of these metallic bases, are in constant use, and constitute some of the most important substances known to the chemist. They are the bases of the most common and useful salts, and an accurate knowledge of their atomic weights is of the utmost consequence to the progress of the science. The principal part of our attention will, therefore, be bestowed on the investigation of the atomic weights of these alkaline compounds. The knowledge of the atomic weights of the bases will follow as a kind of corollary from that of their compounds.

SECT. I.

OF THE ATOMIC WEIGHT OF POTASH AND POTASSIUM.

THERE are two salts of potash, which, when properly prepared, are destitute of water, and consist respectively of water united to nitric acid and sulphuric acid. These are nitrate of potash, and sulphate of potash.

Analysis of nitrate of potash.

1. Nitrate of potash crystallizes in six-sided prisms, terminated by six-sided pyramids. When kept red hot, the nitric acid is gradually dissipated, and pure potash remains behind. It may appear at first sight easy, by this means, to deter-

mine the composition of saltpetre; for the loss of weight would indicate the quantity of nitric acid, while the residual matter in the crucible would be the potash;—and if we were possessed of any vessel upon which red hot saltpetre would not act, and if potash were absolutely fixed in the fire, this method would be a good one;—but I have not been able to obtain satisfactory results by decomposing this salt by heat. The process, which answered best, was to triturate a given weight of saltpetre with twice as much siliceous sand, and to fuse the mixture in a platinum crucible. When 12·75 grains of saltpetre were employed, the loss of weight approached very near 6·75 grains, though it always somewhat exceeded that quantity.

Of sulphate of potash.

2. Sulphate of potash affords an easy method of determining the atomic weight of potash with precision. Before relating the experiment by which this object was attained, it may be proper to remind the reader that the atomic weight of sulphuric acid is 5; and that 13·25 grains of chloride of barium yield a quantity of barytes just capable of neutralizing 5 grains of sulphuric acid.

11 grains of sulphate of potash, and 13·25 grains of chloride of barium, were dissolved in separate portions of distilled water. The two solutions being mixed, a double decomposition took place, and sulphate of barytes precipitated

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in the state of a white powder. The liquid, after it had recovered its transparency from the complete subsidence of this precipitate, was tested by sulphate of soda and muriate of barytes; but neither of these reagents produced the least muddiness or opalescence, showing that the liquid contained neither barytes nor sulphuric acid. From this experiment it is evident, that the sulphuric acid in 11 grains of sulphate of potash, just saturates the barytes from 13·25 grains of chloride of barium. Consequently, it amounts to exactly 5 grains. So that sulphate of potash must be a compound of

Sulphuric acid	5
Potash . .	6
	11

Atomic weight of potash.

But since the salt is neutral, and since 5 is the weight of an integrant particle of sulphuric acid, it is plain that 6 must be the weight of an integrant particle of potash.

Of potassium.

3. The atomic weight of potash being known, it is easy from the experiments made on potassium to determine the atomic weight of that metal. From the experiments of Gay-Lussac and Thenard, it appears that when 100 grains of potassium are put into water, the metal combines with the oxygen of that liquid, and is converted into potash, while the hydrogen gas evolved

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measures 116·38 cubic inches. This experiment was made by plunging a given bulk of potassium into water, and inferring the weight from the known volume and specific gravity of this metal. I have repeated it several times, employing various contrivances to enable me to weigh the potassium; but I was unable to obtain better results than those of the French chemists. I shall therefore employ them, as they are amply sufficient for the object I have in view.

The oxygen gas, which must have united with the 100 grains of potassium, must have amounted to $\frac{116{\cdot}38}{2} = 58{\cdot}19$ cubic inches; the weight of which is 19·72 grains. So that potash, according to these experiments of the French chemists, is composed of

Potassium	100	or	5·121
Oxygen	19·72	-	1
			6·121

The weight of an atom of potash, according to this experiment, is 6·121, and it is a compound of one atom potassium = 5·121, and one atom oxygen. Now, it is obvious, that this atomic weight of potash is a little too high; it should have been 6, and not 6·121. The reason undoubtedly is, that the hydrogen gas evolved was a little below the true quantity. Whoever will take the trouble to repeat the experiment, will be at no loss to account for this deficiency.

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Berzelius took another method of determining the composition of potash. He placed a quantity of amalgam of potassium in water; the amalgam was speedily decomposed, the potassium being converted into potash, and dissolving in the water, while the running mercury remained behind. The potash thus formed was saturated with muriatic acid, the liquid evaporated to dryness, and the residual salt weighed. The difference between the weight of the amalgam and of the running mercury remaining, gave the weight of the potassium; while the weight of the muriate of potash formed, furnished the data for determining the weight of the potash. It is obvious, that the difference between the weight of the potassium and the potash, was the quantity of oxygen with which the potassium had combined. This experiment gave the constituents of potash as follows:

Potassium	100	or	4·889
Oxygen	20·45	-	1
			5·889

According to this experiment, an atom of potassium weighs 4·889, and an integrant particle of potash 5·889. This determination is a little below the truth, while that of the French chemists is a little above it.

The mean of the two gives 5·005 for the atomic weight of potassium. The true weight

is undoubtedly 5; and potash is a compound of 1 atom potassium = 5, and 1 atom oxygen = 1; consequently, its atomic weight is 6, as we found it to be by the experiment related near the beginning of this section.

Peroxide of potassium.

4. Potassium combines with an additional dose of oxygen, and forms a solid yellow substance, which has received the name of *peroxide* of potassium. From the experiments of Gay-Lussac and Thenard, it appears, that 100 grains of potassium, when converted into peroxide, combine with 177 cubic inches of oxygen gas. Now, this is just three times as much as the quantity necessary to convert potassium into potash; for 100 grains of potassium were found to absorb 58·19 cubic inches of oxygen gas when converted into potash — and $\frac{177}{3} = 59$. Peroxide of potassium must, therefore, be composed of

1 atom potassium	= 5
3 atoms oxygen	= 3
	8

And an integrant particle of it must weigh 8.

It deserves attention, that this experiment of Gay-Lussac and Thenard gives the atomic weight of potassium different from their former one. For 59 cubic inches of oxygen gas weigh 20·38 grains; so that potash is composed, according to this experiment, of

Potassium	100	or	4·9068
Oxygen	20·38	-	1
			5·9068

The atom of potassium, by the first experiment, weighs 5·121; by the second 4·9068. The mean of the two is 5·0139; which approaches much nearer the truth than either of the experiments taken singly.

SECT. II.

OF THE ATOMIC WEIGHTS OF SODA AND SODIUM.

THE atomic weight of soda may be determined with the same precision, and nearly in the same manner, as the atomic weight of potash.

Composition of sulphate of soda.

1. Sulphate of soda is a well known transparent salt, which crystallizes with great facility. By a careful analysis of this salt I find its constituents as follows:

1 atom sulphuric acid		5
1 atom soda	.	4
10 atoms water	.	11·25
		20·25

The water of crystallization is not always exactly the same. I have found it amount to 11·28, which exceeds the true atomic quantity by 0·03

grain. This excess of water is mechanically lodged between the plates of the crystals;—it may be got rid of by reducing the crystals to powder, and pressing them between two folds of blotting paper. But, as the salt is very easily rendered anhydrous, it is better to employ it for the experiment which I am going to describe, in that state. It may be rendered anhydrous by placing it for some hours, in the vacuum of an air-pump, along with an open vessel of sulphuric acid—or by exposing it to a moderate heat in a platinum crucible.

Nine grains of anhydrous sulphate of soda, and 13·25 grains of chloride of barium, were dissolved in separate portions of distilled water. The two solutions being mixed, a double decomposition took place, and sulphate of barytes precipitated in the state of a white powder. As soon as the liquid had become transparent, it was tested with sulphate of soda and muriate of barytes, but was not rendered opalescent, nor in the least altered, by either of these reagents. It therefore contained no sensible quantity of barytes or sulphuric acid. From this experiment, it follows, that the sulphuric acid in 9 grains of anhydrous sulphate of soda is just saturated by the barytes from 13·25 grains of chloride of barium. Now, this quantity we know is exactly 5 grains; consequently, anhydrous sulphate of soda is composed of

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Sulphuric acid	5
Soda . .	4
	9

Atomic weight of soda.

Five being the atomic weight of sulphuric acid, and the salt being neutral, 4 must be the atomic weight of soda.

2. The atomic weight of soda being known, it is easy, from the experiments of Gay-Lussac and Thenard, to determine its composition, and to deduce the weight of an atom of sodium. 100 grains of sodium, when plunged into water, were immediately converted into soda, while 198·3 cubic inches of hydrogen gas were evolved. From this experiment, it follows, that when 100 grains of sodium are converted into soda, they combine with 99·15 cubic inches of oxygen gas, or 33·6 grains. This experiment gives us the composition of soda as follows :—

Atom of sodium determined.

Sodium	100	or	2·976
Oxygen	33·6	-	1
			3·976

We see that soda is a compound of 2·976 of sodium and 1 of oxygen ; or of 1 atom sodium and 1 atom oxygen. The atom of sodium, by this experiment, is 2·976, and the atom of soda 3·976. This is a little below the truth ; for we have just seen that the true atomic weight of soda is 4 ; but the experiment is sufficient to satisfy us that

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soda is a compound of 1 atom sodium and 1 atom oxygen; and that an atom of sodium weighs 3.

Berzelius tried to determine the quantity of oxygen which converts a given weight of sodium into soda, by the same method which he followed in determining the composition of potash. The result obtained was, that soda is composed of

Sodium	100	or	2·896
Oxygen	34·52	-	1
			3·896

This result deviates a little farther from the truth than that of Gay-Lussac and Thenard.

Sir H. Davy made a variety of experiments with the same object in view, and drew as a conclusion, that soda is a compound of from 75 to 73 sodium, and from 25 to 27 oxygen. One of his experiments gave him the composition of soda as follows:—

Sodium	100	or	3
Oxygen	33⅓	-	1
			4

Now, this result agrees exactly with the atomic weight of soda, as determined in the first paragraph of this section.

There can be no doubt that the atom of sodium weighs 3—and that soda is a compound of 1 atom sodium and 1 atom of oxygen.

Peroxide of sodium.

3. Sodium, like potassium, combines with an additional dose of oxygen, and forms a solid of a greenish yellow colour, distinguished by the name of peroxide of sodium. From the experiments of Gay-Lussac and Thenard, it appears, that sodium in the peroxide is united with 1½ times as much oxygen as in soda.* Hence, the peroxide is composed of

Sodium	3
Oxygen	1·5
	4·5

So that the atomic weight of this peroxide is 4·5, and it is a compound of 1 atom sodium and 1½ atom oxygen; or of 2 atoms sodium and 3 atoms oxygen. It is curious that soda has a tendency to combine in the same proportion, with several of the acids, that sodium does with oxygen.

SECT. III.

OF THE ATOMIC WEIGHTS OF LITHIA AND LITHIUM.

THOUGH *lithia* has been known for only a few years, and though it has been hitherto procured only in small quantities, yet its properties have

* Recherches Physico-Chem. I. 152.

been examined with so much care, and some of the salts which it forms have been analyzed with such accuracy, that its atomic weight has been ascertained with as much precision as that of any of the alkaline bases. I have examined several of the salts of lithia, but found the sulphate best adapted for a rigid determination of the atomic weight.

Analysis of sulphate of lithia.

1. Sulphate of lithia crystallizes very well by spontaneous evaporation, even when the quantity of it is small. It forms four-sided rectangular prisms with square bases, which are not liable to deliquesce when exposed to the air. Its taste is saline, without any perceptible bitterness. It contains water of crystallization, which is easily driven off by exposing the salt to a heat of about 600°.

This salt was analyzed by Arfwedson, Vauquelin, and Gmelin, in an anhydrous state: but Stromeyer has stated both the saline constituents and the water of crystallization.

According to Arfwedson,* the constituents of this salt are

Sulphuric acid	68·41	or	5
Lithia	31·59	-	2·308
	100·00		

Vauquelin† states its constituents as follows:

* Ann. de Chim. et de Phys. X. 90. † Ibid. VII. 287

Sulphuric acid	69·2	or	5
Lithia	30·8	-	2·225
	100·0		

The salt being neutral, and 5 being the atomic weight of sulphuric acid, the corresponding number for lithia must denote the weight of an atom of that alkali, according to the determination of these chemists. Lithia, consequently, according to the analysis of Arfwedson, weighs 2·308,—according to that of Vauquelin, its weight is 2·225. The mean of these two analyses gives us 2·266 for the atomic weight of lithia. This approaches very near 2·25, which, as I shall show immediately, is the true atomic weight of lithia.

Gmelin's* analysis (when corrected) is as follows:—

Sulphuric acid	67·15	or	5
Lithia	32·85	-	2·416
	100·00		

The atomic weight of lithia derived from this analysis, is higher than that given by Vauquelin, or even by Arfwedson, amounting to 2·416. But, if we compare Gmelin's analysis of carbonate of lithia with his analysis of the sulphate, it will be evident that they cannot be quite ac-

* Gilbert's Annalen, LIX. 238.

curate. The fused carbonate he found a compound of

Carbonic acid	54·46	or	2·75
Lithia	45·54	-	2·2995
	100·00		

So that the atomic weight of lithia, by his analysis of the sulphate, is 2·416, while by the analysis of the carbonate it is only 2·2995. This discordancy would render it hazardous to employ Gmelin's analysis for the determination of the atomic weight of this alkali.

Stromeyer's analysis is more recent than those of the three above named chemists; and it comes nearer the truth than any of the others.* 100 parts of the crystals contain (according to him) 13 parts of water, and the anhydrous salt (correcting the calculations) is a compound of

Sulphuric acid	68·977	or	5
Lithia	31·023	-	2·2488
	100		

The water, when reduced to the atomic proportions, is 1·083, or very nearly one atom.

2. I exposed 8·375 grains of very carefully prepared crystals of sulphate of lithia, to the temperature of 600°, in a platinum crucible, till

* Untersuchungen, I. 435.

the salt ceased to give out moisture. The loss of weight was exactly 1·125 grain, which is equivalent to 1 atom. The 7·25 grains of anhydrous salt were dissolved in a minimum of distilled water, and the liquid was mixed with a solution of 13·25 grains of chloride of barium. After the sulphate of barytes had subsided, the residual liquid was tested with sulphate of soda and muriate of barytes; but neither of these reagents produced any opalescence, showing that it contained neither barytes nor sulphuric acid. Consequently, the sulphuric acid in 7·25 grains of anhydrous sulphate of lithia amounts to exactly 5 grains. The remaining portion of the salt being lithia, it is obvious that the true composition of this salt is as follows:

Sulphuric acid	5	or	1 atom
Lithia . .	2·25	-	1 atom
Water . .	1·125	-	1 atom
	8·375		

Atom of lithia.

Thus, the true atomic weight of lithia is 2·25, and the sulphate contains an atom of each of its constituents.

Atom of lithium.

3. It was ascertained by Sir H. Davy, that lithia, like potash and soda, is a compound of a white coloured metal, called *lithium*, and oxygen. Though no experiments have been made to determine the proportion of these two constituents, there is no difficulty in ascertaining the true

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composition of lithia, now that we know the atomic weight of this alkali and of oxygen. Potash and soda are each of them compounds of 1 atom of oxygen, with 1 atom of potassium and sodium respectively. We shall find that the composition of barytes, strontian, lime, and magnesia, is quite similar. It is reasonable to conclude from this, that lithia is likewise a compound of 1 atom oxygen and 1 atom lithium; consequently, an atom of lithium must weigh 1·25, and lithia must consist of

1 atom lithium	1·25
1 atom oxygen	1
	2·25

SECT. IV.

OF THE ATOMIC WEIGHTS OF BARYTES AND BARIUM.

Barytes has been employed in many of the preceding sections to determine the atomic weight of different bodies, in consequence of the property which it has of forming an insoluble compound with sulphuric acid. It has been already explained, that sulphate of barytes is a compound of

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Sulphuric acid	5
Barytes	9·75
	14·75

From which it is obvious, that 9·75 must be the atomic weight of barytes;—but a few additional observations may be requisite to prevent any obscurity from incommoding the progress of the reader.

Constituents of barytes.

1. When a current of chlorine gas is made to pass over red hot barytes, this gas is absorbed, while at the same time oxygen gas is evolved—and the barytes is changed into chloride of barium. Sir H. Davy, to whom we owe this experiment, ascertained, that for every volume of chlorine gas absorbed by the barytes, half a volume of oxygen gas was evolved. It is obvious that the oxygen gas was displaced from the barytes by the chlorine, and of consequence, the barytes was converted into barium. Half a volume of oxygen gas and a whole volume of chlorine gas, being each equivalent to an atom, it is clear that barytes must be a compound of 1 atom barium and 1 atom oxygen; consequently, an atom of barium weighs 8·75.

2. Muriatic acid was shown, in a preceding chapter, to be a compound of 1 atom of chlorine = 4·5; and 1 atom of hydrogen = 0·125; so that its atomic weight is 4·625.

3. Water was likewise shown to be a com-

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pound of 1 atom oxygen and 1 atom hydrogen, and its atomic weight is 1·125.

4. An integrant particle of anhydrous muriate of barytes weighs 14·375; being composed of

Muriate of barytes.

1 atom muriatic acid	= 4·625
1 atom barytes	= 9·75
	14·375

5. When muriate of barytes is exposed to a red heat, it undergoes a double decomposition. The hydrogen of the acid and the oxygen of the base uniting together, constitute a particle of water, which is driven off by the heat, while the chlorine and the barium remain united together in the state of chloride of barium. For it is obvious, that 14·375 of muriate of barytes may be decomposed into

1 atom water	= 1·125
1 atom chloride of barium	= 13·25
	14·375

6. Whenever chloride of barium is dissolved in water it is again converted into muriate of barytes. A portion of the water is decomposed, the hydrogen of which converts the chlorine into muriatic acid, while the oxygen changes the barium into barytes.

7. Thus, it appears, that whenever muriate of barytes is exposed to a red heat, it is converted

into chloride of barium ; and that when chloride of barium is dissolved in water, it becomes muriate of barytes. We may, therefore, employ 13·25 grains of chloride of barium as an equivalent for 14·375 grains of muriate of barytes, and as capable of yielding 9·75 grains of barytes.

These things being understood and recollected, we are prepared for an experimental investigation of the atomic weight of barytes.

Atomic weight of barytes.

13·25 grains of chloride of barium, and 11 grains of sulphate of potash, were dissolved in separate portions of distilled water, and the two solutions were mixed together. A double decomposition took place, sulphate of barytes precipitated to the bottom of the vessel, while muriate of potash remained in solution. Both of these salts were quite neutral, and the solution contained no traces either of sulphuric acid or of barytes. The sulphate of barytes being collected weighed 14·75 grains ; the solution being evaporated to dryness, left 9·5 grains of chloride of potassium. Now, the weights of these two salts amount to 24·25 grains, which is just equal to the combined weights of the chloride of barium, and sulphate of potash employed in making the experiment.

11 grains of sulphate of potash contain 5 grains of sulphuric acid, which must exist in the 14·75 grains of sulphate of barytes. Consequently, that salt must be a compound of

Sulphuric acid	5
Barytes	9·75
	14·75

The salt being neutral, and 5 being the atomic weight of sulphuric acid, it is plain that 9·75 must be the atomic weight of barytes.

Muriate of barytes is a white, pungent, and disagreeably tasted salt, which crystallizes in very short four-sided prisms with square bases. I find by a careful analysis of these crystals, that they are composed of

1 atom muriatic acid	=	4·625
1 atom barytes	=	9·750
1 atom water	=	1·125
		15·5

If 15·5 grains of it be exposed to a red heat, they are reduced to 13·25 grains; so that the loss sustained, owing to the escape of water, is 2·25 grains. This loss is equivalent to two atoms of water; one of these atoms existed in the salt as water of crystallization; the other atom was formed by the muriate of barytes being converted into chloride of barium.

Peroxide of barium.

Gay-Lussac and Thenard ascertained that when anhydrous barytes is heated in oxygen gas, a portion of the gas is absorbed, and the barytes is converted into a peroxide. This peroxide is

grey; but we have no data to determine how many atoms of oxygen it contains.

SECT. V.

OF THE ATOMIC WEIGHTS OF STRONTIAN AND STRONTIUM.

THE atomic weight of strontian is easily determined by experiments of a similar kind with those related in the last section. It will be sufficient if I describe one of them.

Atom of strontian determined.

1. Nine grains of anhydrous sulphate of soda, and ten grains of chloride of strontium, (that is, muriate of strontian, exposed to a red heat,) were dissolved in separate portions of water. These two solutions being mixed together, a double decomposition took place. Sulphate of strontian precipitated abundantly, and the residual liquid contained a quantity of common salt, which was perfectly neutral, as no change was produced on paper stained with litmus or cudbear. This residual liquid being tested by muriate of barytes, did not give any indication of the presence of sulphuric acid. Nor was it rendered in the least turbid by sulphate of soda, arseniate of soda, or chromate of potash, even when very much concentrated by evaporation. Consequently, it contained no sensible quantity of strontian; the sulphate of strontian being care-

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fully collected and exposed to a red heat, weighed 11·5 grains. Now, it contained all the sulphuric acid in 9 grains of anhydrous sulphate of soda, which is just 5 grains. The remaining 6·5 grains must be strontian. Thus it appears, that sulphate of strontian is composed of

Sulphuric acid	5
Strontian .	6·5
	11·5

5 being the atomic weight of sulphuric acid, and the salt being neutral, 6·5 must be the atomic weight of strontian.

The soda in 9 grains of anhydrous sulphate of soda amounts to 4 grains, which requires for saturation 4·625 grains of muriatic acid, equivalent to 4·5 grains of chlorine—and this must be the quantity of chlorine in 10 grains of chloride of strontium. If from 10 we subtract 4·5, the remainder is 5·5, which indicates the quantity of strontium in 10 grains of this chloride. This 5·5 of strontium, when converted into strontian in the sulphate, becomes 6·5. Hence, it is obvious that strontian is a compound of 1 atom oxygen, and 1 atom strontium; and that an atom of strontium weighs 5·5.

Atom of strontium.

Muriate of strontian crystallizes in long needles, consisting of six-sided prisms, two opposite faces of which are broader than the other four. By

Muriate of strontian.

a careful analysis of this salt, I have ascertained its composition to be as follows:

1 atom muriatic acid	= 4·625
1 atom strontian	= 6·5
8 atoms water	= 9
	20·125

So that an integrant particle of it weighs 20·125. When 20·125 grains of these crystals are exposed to a red heat in a platinum crucible, they lose 10·125 grains of water, which is equivalent to 9 atoms; and there remain behind 10 grains of chloride of strontium, which is equivalent to the weight of an integrant particle of that chloride. Thus, muriate of strontian, like muriate of barytes, loses 1 atom of water more than it contains in the state of water. This atom is produced by the double decomposition of the muriate of strontian into an atom of water, and an atom of chloride of strontium, precisely in the manner explained in the last section, when treating of the conversion of muriate of barytes into chloride of barium by heat.

SECT. VI.

OF THE ATOMIC WEIGHTS OF LIME AND CALCIUM.

The salts of lime are either insoluble in water, or they contain much water of crystallization, of

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which they cannot be completely deprived, without the risk of losing at the same time a portion of their acid. On this account, the method which I was obliged to employ in determining the atomic weight of lime, was rather more complicated than that which gave the atomic weights of the other alkaline bodies contained in this chapter; though it was equally decisive.

Atomic weight of lime determined.

1. 6·25 grains of pure calcareous spar (kept for twenty-four hours at a temperature higher than that of boiling water) were dissolved in muriatic acid, and the solution evaporated to dryness in a low temperature, in order to get rid of all excess of acid. The muriate of lime, thus rendered neutral, was re-dissolved in a small quantity of distilled water. In another portion of distilled water I dissolved 8·75 grains of pure anhydrous carbonate of potash. These two solutions being mixed, a double decomposition took place,—the lime and carbonic acid precipitated in the state of carbonate of lime, while the muriatic acid and potash remained in solution in the state of muriate of potash.

The clear liquid remaining after the precipitation of the carbonate of lime, produced no change in the colour of cudbear pape and consequently contained no sensible quantity of carbonate of potash; and as it was not precipitated by oxalate of ammonia, it contained no sensible quantity of lime.

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The carbonate of lime precipitated, being washed and dried, weighed just 6·25 grains, or exactly the same as the calcareous spar originally dissolved in the muriatic acid. It was obviously a compound of all the lime in 6·25 grains of calcareous spar, and all the carbonic acid in 8·75 grains of anhydrous carbonate of potash.

This carbonate of potash had been procured by exposing pure crystals of bicarbonate of potash to a red heat in a platinum crucible. It has been ascertained that this carbonate is anhydrous, and that it is a compound of

1 atom carbonic acid	= 2·75
1 atom potash	= 6
	8·75

From this it is obvious, that the 6·25 of carbonate of lime contained just 2·75 of carbonic acid, the remainder being lime, it is evident, that this carbonate is composed of

Carbonic acid	2·75
Lime	3·50
	6·25

2·75 being the atomic weight of carbonic acid, and the salt being neutral, 3·5 must be the weight of an atom of lime. It is clear likewise, that calcareous spar is a compound of one atom carbonic acid and one atom lime.

2. If a current of chlorine gas be made to pass through a quantity of lime heated to redness, this alkaline earth is decomposed, oxygen gas is disengaged, and chloride of calcium is formed. Sir H. Davy, to whom we are indebted for this experiment, ascertained that for every half volume of oxygen gas extricated, a whole volume of chlorine gas was absorbed. Now, these two being equivalent, respectively, to one atom, it is obvious that lime must be a compound of one atom oxygen and one atom calcium. Consequently, the atomic weight of calcium is 2·5. Atomic weight of calcium.

3. Muriate of lime may be easily crystallized, by placing a concentrated solution of it under the exhausted receiver of an air pump, over a flat glass vessel containing a quantity of concentrated sulphuric acid. The crystals are large transparent four or six-sided prisms, usually striated longitudinally. They are composed of

1 atom muriatic acid	4·625
1 atom lime . .	3·5
6 atoms water .	6·75
	14·875

When this muriate is cautiously exposed to a heat gradually raised to redness, it may be fused and converted into chloride of calcium with scarcely any loss of chlorine or muriatic acid. In that case it loses 7 atoms of water, 14·875 grains of the crystallized muriate being by this

treatment reduced to 7 grains of chloride of calcium. I shall relate one experiment to show the reader how near to these numerical results I have been able to come. 12·5 grains of pure calcareous spar (containing 7 grains of lime) were dissolved in muriatic acid, in a platinum crucible, the weight of which had been previously determined. The solution was slowly evaporated to dryness, and the dry salt was fused by exposing the salt to a red heat. The fused salt was white and opaque, and weighed 13·98 grains, as nearly as could be determined. Water being poured upon it, there remained undissolved 0·17 grain of a white powder consisting chiefly of carbonate of lime; but containing also one or two flocks of sulphate of lime, apparently derived from a trace of sulphuric acid, in the muriatic acid employed to dissolve the calcareous spar. Now, 0·17 carbonate of lime contain 0·095 lime = 0·0678 calcium, which requires for saturation 0·122 chlorine, making together 0·1898 chloride of calcium; which exceeds the 0·17 grain of carbonate of lime by very nearly 0·02 grain; making (as near as I could determine) almost exactly 14 grains.

Now, these 14 grains contained 2 atoms chlorine = 9, and 2 atoms calcium, which must amount to 5. So that the atomic weight of calcium is obviously 2·5; and lime is a compound of 1 atom oxygen and 1 atom calcium.

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SECT. VII.

OF THE ATOMIC WEIGHTS OF MAGNESIA AND MAGNESIUM.

THE atomic weight of magnesia may be determined in the same way as that of the fixed alkalies. For sulphate of magnesia, which crystallizes in four-sided prisms with square bases, and is perfectly neutral, may be rendered anhydrous by heat, without losing any of its acid.

Atom of magnesia determined.

1. 7·5 grains of anhydrous sulphate of magnesia, and 13·25 grains of chloride of barium, were dissolved in two separate portions of distilled water. The two solutions being mixed together and agitated, a double decomposition took place, sulphate of barytes precipitated, while muriate of magnesia remained in solution. The supernatant liquid, after the sulphate of barytes had subsided, was perfectly neutral. Being tested by sulphate of soda, and muriate of barytes, it did not become in the least muddy by the addition of either of these reagents, showing that it contained neither barytes nor sulphuric acid. Hence, the sulphuric acid in 7·5 grains of anhydrous sulphate of magnesia just saturates the barytes from 13·25 grains of chloride of barium—so that it amounts to precisely 5 grains. The remainder of the salt consisting of magne-

sia, it is evident that anhydrous sulphate of magnesia is a compound of

Sulphuric acid	5
Magnesia	2·5
	7·5

The salt being neutral, and 5 being the atomic weight of sulphuric acid, it is plain that 2·5 must represent the atomic weight of magnesia.

Composition of sulphate of magnesia.

2. By a careful analysis of the crystallized sulphate of magnesia, I have ascertained that it is a compound of

1 atom sulphuric acid	=	5
1 atom magnesia	=	2·5
7 atoms water	=	7·875
		15·375

So that an integrant particle of it weighs 15·375. When 15·375 grains of these crystals are heated properly, the whole water may be driven off without the loss of any sulphuric acid or magnesia;—for the weight of the anhydrous salt is exactly 7·5 grains. 15·375 grains of crystallized sulphate of magnesia just precipitate all the barytes contained in a solution of 13·25 grains of chloride of barium.

Muriate of magnesia.

3. Muriate of magnesia is a deliquescent salt; but it may be obtained in large transparent crys-

tals, which by a careful analysis I find composed as follows :

1 atom muriatic acid	= 4·625
1 atom magnesia	= 2·5
5 atoms water .	= 5·625
	12·75

If it could be rendered anhydrous without the loss of its acid, it would doubtless be reduced to chloride of magnesium, weighing only 6 grains; but this cannot be done; for when the muriate is heated, not only the water, but a considerable portion of the acid flies off and leaves the magnesia. I may state an experiment, however; because it seems to show that a chloride of magnesium might be formed, if the requisite precautions were taken. It was the only successful trial that I made, though my experiments amounted to five or six. 15·31 grains of pure anhydrous carbonate of magnesia, equivalent to 7·29 grains of magnesia, were dissolved in muriatic acid, and the solution being evaporated to dryness, the muriate of magnesia was exposed to an incipient red heat, with every precaution which I could devise to prevent the escape of the muriatic acid. The salt thus treated weighed 13·3 grains, and had a whitish colour. Water being poured upon it, the greater part was dissolved with the evolution of much heat,

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and there remained undissolved 3 grains of pure magnesia. Now, if we suppose the 10·3 grains which dissolved, to have been previously in the state of chloride of magnesium, they must have consisted of

Magnesium	2·575
Chlorine	7·725
	10·300

And 2·575 grains of magnesium are equivalent to 4·29 grains of magnesia. Now, 4·29 + 3 = 7·29, which is the amount of the magnesia originally present in the carbonate employed. It would appear that in this experiment a chloride of magnesium was obtained.

Atom of magnesium.

It is obvious, if the preceding experiment deserves any confidence, that magnesia is a compound of

1 atom magnesium	1·5
1 atom oxygen	1·0
	2·5

And this is corroborated by the following experiment originally made by Sir H. Davy. When magnesia is heated, and a current of chlorine gas passed over it, oxygen is given out, and the magnesia is converted into chloride of magnesium. Now, for every volume of chlorine absorbed, half a volume of oxygen gas is given out. This shows that magnesia contains only 1

atom of oxygen. Consequently, the weight of an atom of magnesium must be 1·5.

From the details contained in the different sections of this chapter, it is evident that the fixed alkalies and alkaline earths are all analagous substances, being each a compound of one atom of a metallic basis, and one atom of oxygen. Potassium, sodium, and barium combine with two doses of oxygen; though this has not been shown to hold with the other four bases contained in this chapter, yet it is probable, from the striking analogy between the properties of all these bodies, that they will be found hereafter to be in the same predicament.

Lithia is the lightest, and barytes the heaviest of these bodies. It may be worth while to subjoin a tabular view of the atomic weights of the metallic bases and the alkalies, arranged according to the weight.

Table of the atoms of the alkaline metals and alkalies.

BASES.	ATOMIC WEIGHTS.	ALKALIES.	ATOMIC WEIGHTS.
Lithium	1·25	Lithia	2·25
Magnesium	1·5	Magnesia	2·5
Calcium	2·5	Lime	3·5
Sodium	3	Soda	4
Potassium	5	Potash	6
Strontium	5·5	Strontian	6·5
Barium	8·75	Barytes	9·75

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CHAP. IX.

OF THE ATOMIC WEIGHTS OF THE EARTHS PROPER.

There are four substances, which are now considered as metallic oxides, but which were long distinguished by the name of *earths proper*. When pure, they have the form of white tasteless powders,—insoluble in water, though capable of forming solid hydrates with that liquid. They combine readily with the acids, and form salts, which redden vegetable blues, and are decomposed by exposure to a red heat. These four bodies are *alumina*, *glucina*, *yttria*, and *zirconia*. We shall devote this chapter to the investigation of the atomic weights of these bodies.

SECT. I.

OF THE ATOMIC WEIGHT OF ALUMINA.

In a paper inserted in the Annals of Philosophy (Second Series), Vol. III. p. 61. I gave the result of a very laborious analysis of alum, from which I drew, as a conclusion, that the atomic weight of alumina was 2·25. Since that time, Mr.

R. Philips has published some experiments on the sulphate of alumina, from which he considers it most probable that the atomic weight of alumina is 3·375. This opinion, from a man of Mr. Philips' precision and extensive chemical knowledge, induced me to repeat the whole of my experiments, and to extend my researches as far as possible, in order to throw as much light as I could upon this very important, but difficult subject. I shall in this section lay the result of my experiments before the reader.

Methods of determining the atom of alumina.

There are three methods, by means of which we may hope to come to an accurate conclusion respecting the atomic weight of alumina. 1*st*. It enters as a constituent into a great number of crystallized minerals, which appear to be definite combinations of acids and bases. By a rigid analysis of these minerals in a state of purity, and by our knowledge of the atomic weights of all the other constituents, we may determine the quantity of alumina which unites with a determinate weight of the acid in the mineral, which will give us the atomic weight of alumina, or at least an approximation to it. 2*d*. Several artificial salts exist, containing alumina as one of the constituents. A precise analysis of these salts, in a state of purity, must lead to an accurate determination of the saturating power of alumina, and consequently give us its atomic weight. 3*d*. Alumina enters into definite combinations with

water, and forms a variety of hydrates; a precise analysis of which will also throw considerable light upon the atomic weight of alumina. Let us see what number we shall obtain for the atomic weight of alumina, deduced in each of these ways.

1. From the composition of minerals.

I. The number of minerals containing alumina as an essential constituent is very considerable. The acid substance with which it is most commonly combined is silica. It occurs, indeed, combined with phosphoric acid, fluoric acid, and mellitic acid; but the mode of analyzing such combinations is still too imperfect to render it safe for us to trust to them for determining a point of such importance. Beryl would be an excellent mineral for our purpose, were it not that the atomic weight of glucina has not been yet determined with sufficient precision to allow us to employ it in investigating the atomic weight of alumina. I shall, therefore, satisfy myself with the following mineral species, all of which have been analyzed with much care, and in a state of as great purity as possible; but I have investigated the atomic weight of alumina from a much greater number of species, and have obtained very nearly the same result as from the species which we are going to examine.

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1. NEPHELINE.

Nepheline

It was stated in p. 177 of this work, that from the late analysis of nepheline, by Arfwedson, its constituents are as follows:

Silica	.	44·11
Alumina	.	33·73
Soda	.	20·46
Water	.	0·62
		98·92

It was shown that nepheline is a compound of 3 integrant particles of silicate of alumina, and 1 integrant particle of sesquisilicate of soda. It was shown that the portion of silica united to the alumina was 29·17 grains. Now,

29·17 (the quantity of silica) : 33·73 (the alumina) : : 2 (atom of silica) : 2·3126 = atom of alumina.

Gives 2·3126.

2. KARPHOLITE.

Karpholite

This rare mineral occurs in the Schlackenwald in Bohemia, and was named by Werner, from the resemblance of its colour to straw. It occurs in very fine needles, which usually diverge from a point. Its specific gravity is 2·923; it seems to be rather soft. Stromeyer,* from a very careful analysis of this mineral, has given its constituents as follows:

* Untersuchungen, I. p. 410.

Silica . . .	36·154
Alumina . . .	28·669
Deutoxide of manganese	19·160
Peroxide of iron . .	2·290
Lime . . .	0·271
Fluoric acid . .	1·470
Water . . .	10·780
	98·794

It appears from Professor Stromeyer's experiments on this mineral, that it is usually mixed with particles of fluor spar. To the presence of this spar in minute quantities, I have no doubt that the lime and the fluoric acid found by Stromeyer owe their origin. It is true that the lime and fluoric acid were not found in the same proportions as they exist in fluor spar; for I shall show, in a subsequent chapter of this work, that fluate of lime is a compound of

Fluoric acid	1·25
Lime .	3·5
	4·75

But the accurate analysis of this mineral is attended with so much difficulty, that much greater errors than those here suspected have been committed by the most expert analysts.

The manganese was obtained, and weighed by Stromeyer, in the state of deutoxide; but it must have existed in the mineral, in the state of

protoxide. Now, the atomic weight of protoxide of manganese is 4·5, and of deutoxide 5. If we reduce the manganese in the mineral in this proportion, the quantity of protoxide will be 17·244 grains.

The peroxide of iron is probably foreign to the constitution of the mineral, and may have been introduced by percollation.

Now, if we suppose every atom of alumina to be united to an atom of silica, and every atom of protoxide of manganese to be united to 1½ atom of silica, we shall obtain data for calculating the constituents of the mineral. We shall consider an atom of silica as 2, an atom of alumina as 2·25, and an atom of protoxide of manganese as 4·5.

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 28·669 (alumina in the mineral) : 25·483 = silica united to the alumina.

(2.) 4·5 (atom of protoxide) : 3 (atom and half of silica) : : 17·244 (protoxide in the mineral) : 11·496 = silica united to the manganese.

But 25·483 + 11·496 = 36·979, which exceeds the whole silica found in the mineral by 0·825 grain; but $\frac{1}{3}$ of the silica is united to the manganese: consequently, 0·257 of this excess must be referred to that portion of the silica. There remains 0·568, which must be subtracted from the 25·483 grains of silica, given by theory

as united to the alumina; so that the quantity of silica actually united with the alumina, according to Stromeyer's analysis, is 24·915. Now,

24·915 : 28·669 : : 2 (atom of silica) : 2·3013 = atomic weight of alumina. Gives 2·3013.

3. HARMOTOME.

This mineral, which occurs in a state of great purity in the lead mine at Strontian, in Argyleshire, was found, by Klaproth, to be composed of the following constituents: Harmotome

Silica . .	49
Alumina .	16
Barytes . .	18
Water . .	15
	98

Let us consider this mineral as a compound of 3 integrant particles of trisilicate of alumina, and 1 integrant particle of bisilicate of barytes. Then,

(1.) 2·25 (atom of alumina) : 6 (three atoms silica) : : 16 (alumina in the mineral) : 42·666 = silica united to alumina.

(2.) 9·75 (atom of barytes) : 4 (two atoms silica) : : 18 (barytes in the mineral) : 7·384 = silica united to barytes.

But 42·666 + 7·384 = 50·05; and this exceeds the silica found in the mineral by 1·05 grain.

The silica united to the barytes being ⅓th of the whole, ⅓th of this excess must be referred to that portion. There remains 0·9, which must be subtracted from the 42·666 grains of silica, given by theory as united to the alumina. This being subtracted, leaves 41·766 for the silica actually combined with the alumina, according to Klaproth's analysis. Now,

Gives 2·2985

41·766 : 16 : : 6 : 2·2985 = atomic weight of alumina.

4. MEIONITE.

Meionite

Of this mineral, which occurs most abundantly on Monte Somma, near Naples, but which has been found also in other places, and indeed is probably identical with scapolite, we have several very careful analyses.*

According to the experiments of Dr. L. Gmelin of Tubingen, its constituents are as follows :†

Silica . . .	40·8
Alumina . .	30·6
Lime . . .	22·1
Soda, with some lithia	2·4
Oxide of iron .	1·0
Carbonic acid and loss	3·1
	100·0

* The mineral analyzed by Arfwedson, from which Berzelius has taken his notion of the composition of meionite, was obviously a leucite.

† Schweigger, XXV. 36.

By comparing this analysis with the two following, it will appear probable that the alkali, oxide of iron, and carbonic acid, are merely accidental ingredients; and that silica, alumina, and lime, are the only essential constituents.

Let us consider meionite as a compound of 2 integrant particles of silicate of alumina and 1 integrant particle of silicate of lime; and let us calculate its constitution.

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 30·6 (alumina in the mineral) : 27·2 = silica united to alumina.

(2.) 3·5 (atom of lime) : 2 : : 22·1 : (lime in the mineral) : 12·62 = silica united to the lime.

But 27·2 + 12·62 = 39·82. Now, the silica actually found in the meionite exceeds this by 0·98 grain.

The silica united to the lime amounts to $\frac{1}{3 \cdot 15}$th of the whole; consequently, $\frac{1}{3 \cdot 15}$th of 0·98 or 0·311, belongs to the silica united to the lime. There remains 0·669, which being added to the 27·2, makes 27·869 for the silica united to the alumina in meionite by Gmelin's analysis. Now

27·869 : 30·6 : : 2 : 2·196 = atomic weight of alumina.

Professor Stromeyer analyzed some very pure specimens of meionite from Monte Somma, and found the constituents as follows:*

* Untersuchungen, I. 580.

Silica . . .	40·631
Alumina	32·726
Lime . . .	24·245
Potash with some soda	1·812
Oxide of iron . .	0·182
	99·496

Here the alkali differs both in quantity and kind from that found by Gmelin, and the oxide of iron is not quite $\frac{1}{3}$th of the quantity obtained by that chemist. Let us calculate the composition of this mineral, on the same supposition as we made when calculating the result of Gmelin's.

(1.) 2·25 : 2 : : 32·726 : 29·08 = silica united to the alumina.

(2.) 3·5 : 2 : : 24·245 : 13·854 = silica united to lime.

But 29·08 + 13·854 = 42·934, which exceeds the silica found in the mineral by 2·403 grains.

The silica united to the lime is $\frac{1}{3\cdot09}$th of the whole. Now $\frac{1}{3\cdot09}$th of 2·403 is 0·777, which being subtracted from 2·403 leaves 1·626 to be taken from the 29·08, making 27·454 for the amount of the silica actually united to the alumina. Now,

27·454 : 32·726 : : 2 : 2·3841 = atomic weight of alumina.

Professor Stromeyer likewise analyzed a specimen of meionite from Sterzing in the Tyrol, and found its constituents as follows :*

* Untersuchungen, I. 590.

Silica . . .	39·915
Alumina . .	31·970
Lime . . .	23·856
Potash with some soda	0·894
Protoxide of iron .	2·242
Protoxide of manganese	0·174
Water . . .	0·949
	100·000

The variation in the proportion of alkali and oxide of iron is equally conspicuous in this analysis. Let us calculate the constitution of the mineral on the former supposition.

(1.) 2·25 : 2 : : 31·97 : 28·417 = silica united to alumina.
(2.) 3·5 : 2 : : 23·856 : 13·632 = silica united to lime.

But 28·417 + 13·632 = 42·049, which exceeds the quantity of silica present in the mineral by 2·134 grains.

The silica united to the lime is $\frac{1}{3\cdot08}$th of the whole. Now $\frac{1}{3\cdot08}$th of 2·134 = 0·69; and 2·134 −0·69 = 1·444, which must be subtracted from the 28·417, leaving 26·973. And

26·973 : 31·97 : : 2 : 2·3705 = atomic weight of alumina.

We have obtained three different atomic weights of alumina, namely,

1. From Gmelin's analysis . . .	2·1960	
2. From Stromeyer's analysis of Monte Somma meionite	2·3841	
From ditto of Tyrol meionite . .	2·3705	
	3) 6·9506	
Mean . . .	2·3168	Gives 2·3168.

5. SCAPOLITE.

Scapolite

We have a very careful analysis of this mineral in a state, apparently, of great purity, by Mr. Nordenskiöld.* He found its constituents as follows:—

Silica . .	43·83
Alumina .	35·43
Lime . .	18·96
Water . .	1·03
	99·25

The only difference between the composition of meionite and scapolite seems to be, that the former contains only 2 integrant particles of silicate of alumina united to 1 integrant particle of silicate of lime, while the latter contains 3.

Let us calculate the constitution of this mineral on the same supposition as of meionite:

(1.) 2·25 : 2 : : 35·43 : 31·049 = silica united to alumina.
(2.) 3·5 : 2 : : 18·96 : 10·834 = silica united to lime.

Now, 31·049 + 10·834 = 41·883, which is less than the silica found in the mineral by 1·947 grain. Of this surplus, ⅛th, or 0.487 must be united to the lime—the remaining 1·460 grain must be added to the 31·049, making 32·409. And

Gives 2·0580.

32·409 : 35·43 : : 2 : 2·0580 = atomic weight of alumina.

* Bidrag till Närmare Kännedom af Finland's Mineralier och Geognosie, p. 63.

6. SCOLEZITE.

This mineral was analyzed with great care by Gehlen and Fuchs, who, from a mean of many trials, state its constituents as follows: Scolezite.

Silica	46·4
Alumina	25·7
Lime	14·2
Water	13·6
	100·0

I have analyzed various specimens of scolezite; but only one of them was quite free from soda, and its constituents were almost exactly the same as those found by Gehlen and Fuchs. In the other specimens the quantity of soda varied from 0·5 to 1·5 per cent.; showing that the mineral contained a mixture of natrolite.

Let us suppose that scolezite is a compound of 3 integrant particles of silicate of alumina and 1 integrant particle of trisilicate of lime, with 3 atoms of water, and let us see what its constituents will be on that supposition.

2·25 : 2 : : 25·7 : 22·844 = silica united to alumina.
3·5 : 6 : : 14·2 : 24·3428 = silica united to lime.

Now, 22·844 + 24·3428 = 47·1868, which surpasses the silica actually found in scolezite by 0·6868.

The silica united to the lime is $\frac{1}{1\cdot93}$ of the

whole; and $\frac{1}{1\cdot93}$d part of 0·6868 = 0·3557. This being subtracted from 0·6868 leaves 0·3311, which must be taken from 22·844, leaving 22·513 for the silica actually combined with the alumina in the mineral. And

Gives 2·2831. 22·513 : 25·7 : : 2 : 2·2831 = the atomic weight of alumina.

7. BUCHOLZITE.

Bucholzite From the account of this mineral given in page 175 of this work, it appears that its constituents, according to Brande's analysis, are as follows:

Silica	46
Alumina . . .	50
Oxide of iron . . .	2·5
Potash	1·5
	100·0

And that the silica united to the alumina in this mineral is 44·391 grains. Now,

Gives 2·2527. 44·391 : 50 : : 2 : 2·2527 = an atom of alumina.

8. LEUCITE.

Leucite This mineral, which abounds so much in the neighbourhood of Mount Vesuvius, and which always occurs crystallized, was found by Arfwedson to be composed of

Silica	56·1
Alumina . . .	23·1
Potash . . .	21·15
Oxide of iron . .	0·95
	101·3

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Let us calculate the composition of this mineral, on the supposition that each of the three bases are combined with two atoms of silica, constituting as many bisilicates:

(1.) 2·25 : 4 : 23·1 : 41·066 = silica united to alumina.
(2.) 6 : 4 : : 21·15 : 14·1 = silica united to potash.
(3.) 4·5 : 4 : : 0·95 : 0·844 = silica united to iron.

Now, 41·066 + 14·1 + 0·844 = 56·01, which is less than the silica actually found in the mineral by 0·09 grain.

The silica united to the potash and the iron amounts to $\frac{1}{3\cdot748}$th of the whole. The $\frac{1}{3\cdot748}$th of 0·09 is 0·024, which, being subtracted, leaves 0·066 to be added to 41·066, in order to have the silica actually united to the alumina in the mineral, it will amount to 41·132 grains. And

41·132 : 23·1 : : 4 : 2·2464 = atomic weight of alumina. Gives 2·2464.

9. THOMSONITE.

This mineral, which hitherto has been found only in the Kilpatrick hills, near Glasgow, and which had been considered as a mesotype, has been constituted into a new species by Mr. Brooke, on account of the peculiar form of its primary crystal. I made a very careful analysis of this mineral,* and found its constituents as follows: Thomsonite

* Annals of Philosophy, XVI.

Silica . . .	36·8
Alumina . .	31·36
Lime . . .	15·4
Magnesia . .	0·2
Peroxide of iron .	0·6
Water . . .	13·0
	97·36

Let us consider it as a compound of three integrant particles of silicate of alumina and one integrant particle of silicate of lime, together with $2\frac{1}{2}$ atoms of water; and let us calculate its composition according to that opinion.

(1.) 2·25 : 2 : : 31·36 : 27·875 = silica united to alumina.
(2.) 3·5 : 2 : : 15·4 : 8·8 = silica united to lime.

Now, 27·875 + 8·8 = 36·675, which is less than the silica found in the mineral by 0·175 grain.

The silica united to the lime is $\frac{1}{4}$th of the whole. Now, $\frac{3}{4}$ths of 0·175 = 0·132, which must be added to the 27·875, in order to have the silica actually united to the alumina in the mineral; this makes 28·007. And

Gives 2·2395. 28·007 : 31·36 : : 2 : 2·2395 = atomic weight of alumina.

10. NATROLITE.

Natrolite This mineral, which corresponds with the *mesotype* of Brooke, was analyzed with great care by Gehlen and Fuchs. They found its composition, from a mean of many experiments, as follows:

Silica . . .	48
Alumina . .	26·5
Soda . . .	16·2
Water . . .	9·3
	100·0

I analyzed a beautifully crystallized and pure specimen, which I received from Mr. Heuland, and found its composition almost identical with the preceding analysis.

Let us calculate the composition of this mineral, on the supposition that it is a compound of 3 integral particles of silicate of alumina, and 1 integrant particle of trisilicate of soda, with 2 atoms of water.

(1.) 2·25 : 2 : : 26·5 : 23·555 = silica united to alumina.
(2.) 4 : 6 : : 16·2 : 24·3 = silica united to soda.

Now, 23·555 + 24·3 = 47·855, which is less than the silica found in the mineral by 0·145 grain. One half of the silica being united to the lime, it is obvious that, in order to have the true quantity of silica united to the alumina in natrolite, we must add 0·0725 to the 23·555 grains, given by theory. And

23·6275 : 25·7 : : 2 : 2·1754 = atomic weight of alumina. Gives 2·1754.

11. FELSPAR.

Felspar consists essentially of silica, combined Felspar

with alumina of potash. It has been often analyzed; but the different results obtained do not well agree with each other. The reason is, that felspar almost always occurs in granite, which is a compound rock; and the other constituents, doubtless, mix themselves with it in greater or smaller proportions. According to the analysis of felspar by Rose, which is one of the latest and most careful that have been made, the constituents of felspar are as follows:

Silica . . .	66·75
Alumina . . .	17·50
Potash . . .	12·00
Lime . . .	1·25
Oxide of iron . .	0·75
	98·25

Let us suppose that all the bases are combined with silica, and in the state of trisilicates, except potash, which is a quadrosilicate; and let us calculate its constitution according to that supposition.

(1.) 2·25 : 6 : : 17·5 : 46·666 = silica united to alumina.
(2.) 6 : 8 : : 12 : 16 = silica united to potash.
(3.) 3·5 : 6 : : 1·25 : 2·143 = silica united to lime.
(4.) 4·5 : 6 : : 0·75 : 1 = silica united to oxide of iron.

Now, 46·666 + 16 + 2·143 + 1 = 65·809, which is less than the silica in the mineral by 0·941.

The silica united to the potash, lime, and iron,

amounts to $3 \cdot 43\frac{1}{776}$th part of the whole. And the $3 \cdot 33\frac{1}{776}$th part of 0·941 = 0·273, which being taken from 0·941 leaves 0·668, which must be added to the 46·666 given by theory. Now

47·334 : 17·5 : : 6 : 2·2183 = atomic weight of alumina. Gives 2·2183.

12. ALBITE.

Albite is a name given to a mineral which was long confounded with felspar. Eggertz * first pointed it out as a distinct mineral; it was afterwards analyzed by Stromeyer from Chesterfield in North America, by whom it received the name of *kieselspath*.† Mr. Brookes has called it *cleavelandite*.‡ Rose has given a minute description of the crystals of this mineral, which differ a good deal from those of felspar. Albite

Stromeyer found an uncrystallized specimen from North America composed of

Silica . . .	70·676
Alumina . . .	19·801
Soda . . .	9·056
Lime . . .	0·235
Oxide of iron and manganese	0·111
	99·879

Rose found the specific gravity of albite to vary from 2·608 to 2·619. The constituents of the crystals he found

* Afhandlingar, V. p. 27. † Untersuchungen, p. 300.
‡ Introduction to Crystallography, p. 459.

Silica .	68·46
Alumina .	19·30
Soda .	9·12
Lime .	0·68
Oxide of iron	0·28
	97·84*

Let us suppose the bases combined with silicon in the state of trisilicates, and let us calculate the composition on that supposition from Rose's analysis.

(1.) 2·25 : 6 : : 19·3 : 51·466 = silica united to alumina.
(2.) 4 : 6 : : 9·12 : 13·68 = silica united to soda.
(3.) 3·5 : 6 : : 0·68 : 1·165 = silica united to lime.
(4.) 4·5 : 6 : : 0·28 : 0·373 = silica united to protoxide of iron.

Now, 51·466 + 13·68 + 1·165 + 0·373 = 66·684, which is less than the silica in the mineral by 1·776 grain. It is not improbable that, if the loss, amounting to rather more than two per cent., and which was more likely to fall upon the bases than the silica, had not taken place, this excess of silica would not have occurred in our calculation. But let us see what the atomic weight of alumina will be, supposing the analysis accurate.

The silica united to the soda, lime, and oxide of iron is $\frac{2}{3}\frac{1}{7}$ part of the whole; and $\frac{2}{3}\frac{1}{7}$ part of 1·776 = 0·655, which being taken from 1·776

* Gilbert's Annalen, LXXIII. 186.

leaves 1·121 to be added to the 51·466 given by theory. Now, 52·587 : 19·3 : : 6 : 2·202 = atomic weight of alumina. Gives 2·202.

The 12 preceding minerals constitute a sufficient number to enable us to approach pretty nearly to the atomic weight of alumina. That weight comes out somewhat differently from each mineral. This may be partly occasioned by small errors in the analyses; but it is owing chiefly to impurities existing in the specimens analyzed, the presence of which we have no means of determining. If a mineral contains mixed with it some silica, or a portion of any stone containing more silica than itself, the atomic weight of the alumina will come out too high. The contrary will be the case, when the mineral contains an excess of alumina, or of a stone containing more alumina than the specimen now under examination. An accurate knowledge of the rock from which the specimen was taken, and of the minerals accompanying it, might throw some light upon the foreign matter most likely to be present. But this has not yet been sufficiently attended to;—meanwhile, it is probable, that the errors in the atomic weight of alumina, resulting from these foreign matters, will be on different sides in different analyses; consequently, the mean atomic weight from all the twelve analyses given above will come near the truth. Let us therefore see what

atomic weight of alumina will be derived from that mean.

1.	Nepheline gives the atomic weight	2·3126
2.	Karpholite	2·3013
3.	Harmotome	2·2985
4.	Meionite	2·3168
5.	Scapolite	2·0580
6.	Scolezite	2·2831
7.	Bucholzite	2·2527
8.	Leucite	2·2464
9.	Thomsonite	2·2395
10.	Natrolite	2·1754
11.	Felspar	2·2183
12.	Albite	2.2020
		12)26·9046

Mean gives 2·24205. Atomic weight of alumina . 2·24205

The reader will observe that the greatest atomic weight of alumina is deduced from meionite, and amounts to 2·3168, which is very far short of 3·375, the atomic weight pitched upon by Mr. Phillips. The least weight is 2·0580, which is derived from scapolite.

Upon the whole, the atomic weight of alumina derived from the constitution of these minerals, though it would be hazardous to consider it as quite exact, cannot be very far from the truth;—and it differs from 2·25 by a very small fraction.

2. From the analysis of alum. II. The aluminous salt most easily obtained

in a state of purity, and in regular crystals fit for examination, is *alum*. Of this triple salt there are several species; for it consists of a certain number of integrant particles of sulphate of alumina combined with sulphate of potash, or sulphate of soda, or sulphate of ammonia, or sulphate of magnesia, and perhaps of some other soluble sulphate which I have not tried. The crystals of alum consist of regular octahedrons, and neither the figure nor the taste of the salt is altered by substituting any of the above named sulphates for the others. The species of alum which I chose as upon the whole of easiest analysis, and capable of being obtained with the greatest facility, was the common alum of this country, composed of sulphuric acid, alumina, potash, and water, or of sulphate of alumina and sulphate of potash, united together with a certain quantity of water of crystallization. As the analysis of this salt was attended with considerable difficulty, but was made with the utmost possible attention to precision, it will be proper to give a somewhat detailed account of it.

1. 60·875 grains of pure alum crystals were dissolved in hot water, and the liquid was mixed with a solution of 53 grains of chloride of barium. A double decomposition immediately took place, and sulphate of barytes precipitated to the bottom: when the supernatant liquid had become transparent and colourless, it was tested by sul-

phate of soda and muriate of barytes, but was not affected by either; showing that it contained no sensible quantity of barytes or sulphuric acid. It follows from this experiment, that the sulphuric acid in 60·875 grains of alum is just saturated by the barytes from 53 grains of chloride of barium. But 53 is equal to 13·25 × 4; and 13·25 grains of chloride of barium require just 5 grains of sulphuric acid to saturate all the barytes which they yield. It is obvious from this, that 60·875 grains of alum contain exactly 20 grains of sulphuric acid.

2. 60·875 grains of alum crystals were put into a platinum crucible, which was left for an hour on a hot sand bath. After it had been reduced to the state of burnt alum by the loss of its water of crystallization, it was introduced into a wind furnace, and kept for an hour in a bright red heat. The loss of weight sustained was 43·62 grains.

The alum thus treated, was digested in distilled water, and then thrown upon the filter. The alumina left upon the filter was washed till the liquid which passed through ceased to precipitate muriate of barytes. The liquid which passed through the filter was concentrated on the sand bath, and then precipitated by muriate of barytes. The sulphate of barytes obtained, after being washed, dried, and heated to redness, weighed 13·28 grains, which is equivalent to

4·504 grains of sulphuric acid; if we add this to the original loss, we obtain 48·124 grains for the amount of the water and sulphuric acid in 60·875 grains of alum. Deducting the 20 grains of sulphuric acid which we know to be present, there remain 28·124 grains for the water of crystallization.

But an integrant particle of water weighs 1·125, and $1{\cdot}125 \times 25 = 28{\cdot}125$. From this it is obvious, that 60·875 grains of alum contain 28·125 grains of water, which is equivalent to 25 atoms.

3. 60·875 grains of alum crystals were exposed in a platinum crucible to the heat of the sand bath, and afterwards to a dull red heat for an hour. Distilled water was poured upon the residual matter in the crucible in successive portions, and digested on it till it ceased to take up any thing; this water being evaporated to dryness, left 11 grains of sulphate of potash. Hence, 60·875 grains of alum contain 6 grains of potash. We see, too, that one-fourth of the sulphuric acid is united to the potash: the remaining three-fourths must be in combination with the alumina.

4. To obtain the alumina, 60·875 grains of alum were dissolved in distilled water, and to the solution was added the quantity of carbonate of potash just necessary to saturate 15 grains of sulphuric acid. The experiment was repeated

with carbonate of soda and carbonate of ammonia. Six experiments made in this way gave the mean quantity of alumina from 60·875 grains of alum, equal to 6·746 grains; but the true quantity is obviously 6·75 grains: because this small addition is necessary to complete the weight of the alum.

From the preceding detail it is evident that alum is composed of

Sulphuric acid	20
Alumina .	6·75
Potash .	6
Water .	28·125
	60·875

One integrant particle of the sulphuric acid is united to the potash, and three to the alumina. It is obvious from this, that 6·75 must represent the weight of three atoms alumina. Consequently, the weight of alumina is $\frac{6·75}{3} = 2·25$.

Atomic weight = 2·25.

The composition of alum may be stated somewhat differently. For it is obviously composed of

3 atoms sulphate of alumina	= 21·75
1 atom sulphate of potash	= 11
25 atoms water . .	= 28·125
	60·875

The analysis of alum just given was made by

me during the course of the summer of 1821, and was repeated so frequently that I considered myself as quite certain of its accuracy. But after Mr. Phillips published his experiment on sulphate of alumina, and his suspicion that 3·375 was the true weight of an atom of alumina, I resolved to repeat the whole again. This I accordingly did during the summer of 1823. The result which I obtained may be considered as absolutely identical, for the only differences took place in the second decimal place; and the ratios of the constituents of alum deduced from this second analysis, did not deviate $\frac{1}{1000}$th part from those of the preceding analysis.

If the weight of alumina were 3·375 instead of 2·25, we should obtain from 60·875 grains of alum no less than 10·125 grains of alumina, instead of 6·75, which I obtained; so that I must have lost more than 30 per cent. of the alumina; which, from the care with which the experiment was made, I consider as impossible.

But my analysis of alum is corroborated and confirmed by the analysis of this salt made previously by Berzelius. When we correct his statements by means of the more accurate data given in this work, his analysis of alum is as follows:*

* Ann. de Chim. LXXXII. 258.

Sulphuric acid	33·85	or	20·6060
Alumina .	10·86	-	6·5958
Potash .	9·90	-	6·0266
Water .	45·00	-	27·3940
	99·61		60·6224
Loss			0·2526
			60·8750

According to this analysis, 3 atoms of alumina weigh 6·5958. Consequently, the weight of the atom of alumina is 2·1986, which is a little less than the result of my analysis of alum.

In a subsequent chapter of this work, when I come to treat of the salts of alumina, it will be seen that the atomic weight of alumina just given, is corroborated by many other aluminous salts which have been subjected to examination.

Mr. Phillips' experiment respecting the atom of alumina

Mr. Phillips' opinion, that the atomic weight of alumina is 3·375, seems, as far as I can judge, to be founded on the following experiment. He found that when moderately diluted, sulphuric acid was digested for a long time upon an excess of recently precipitated alumina, till it refused to take up any more;—the liquid, when filtered, had a tendency to precipitate a peculiar sulphate of alumina in white flocks;—the liquid, when dropped into water, rendered it milky, and a white sediment was deposited. He analyzed

this sulphate of alumina, and found it composed of

Sulphuric acid	40
Alumina .	40·85*

This he considers as inconsistent with 2·25 being the atomic weight of alumina. But if 3·375 be the atomic weight of that earth, he conceives that his salt was a compound of

2 atoms sulphuric acid	10	or	40
3 atoms alumina .	10·125	-	40·5
	20·125		

But this is not the only view of the subject which may be taken.

I may observe, in the first place, that alumina is a much weaker base than any of the other earths or alkaline bodies treated of in the preceding chapter. Now, it is a remarkable circumstance, which has been particularly illustrated by Berzelius, that weak bases have the property of combining in a much greater number of proportions with acids than strong bases. I have ascertained by experiment that alumina and sulphuric acid may be united in three proportions; namely, Explained.

1 atom acid + 1 atom alumina
1 atom acid + 2 atoms alumina
1 atom acid + 3 atoms alumina

* Annals of Philosophy (second series) IV. 280.

The first of these salts constitutes common sulphate of alumina, and it is an essential constituent of alum. The third of these salts is the mineral found in Sussex and other places, and known by the name of aluminite. For Stromeyer has shown that it is a compound of 1 atom sulphuric acid, 3 atoms alumina, and 9 atoms water. If potash be poured into a boiling hot solution of alum, an earthy precipitate falls, precisely similar in its nature with the substance which chemists formerly called *alum saturated with its earth.* This precipitate is a compound of 1 integrant particle of sulphate of potash, and 3 integrant particles of trisulphate of alumina, as was first proved by Riffault.* I find that the second of these salts, to which I give the name of disulphate of alumina, may be obtained by a process similar to the one followed by Mr. Phillips; but not carried so far. It is soluble in water, and still possesses an astringent and sweetish sour taste.

Mr. Phillips' salt was a mixture or compound of disulphate of alumina and trisulphate of alumina, in the proportion of 3 atoms of the former salt to 1 atom of the latter. It was the trisulphate which precipitated when the solution was poured into water; and it was its tendency to fall down that explains the phenomena which

* Ann. de Chim. et de Phys. XVI. 355.

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Mr. Phillips considers so unaccountable. I need hardly observe that

	SULPHURIC ACID.		ALUMINA.
3 atoms disulphate contain	15	+	13·5
1 atom trisulphate . .	5	+	6·75
Total . . .	20	+	20·25

Now, this is equivalent to

Sulphuric acid	40
Alumina	40·5

—the very theoretic proportions which Mr. Phillips deduces from an erroneous atomic weight of alumina.

3. From the hydrates of alumina.

III. When alumina is precipitated from an alkaline solution, collected on a filter, well washed, and allowed to dry spontaneously on the filter in a dry warm room, a hydrate is obtained, composed of equal weights of alumina and water. This is an experiment which I have frequently made in Edinburgh and in London, where I was in the habit of working in a room elevated considerably above the ground; but in Glasgow, where my laboratory is in a ground floor situated in a clay soil, and consequently rather damp, I have found it much more difficult to obtain correct results, at least during the summer of 1823, which was uncommonly cold and wet, when I was occupied with this investigation. I shall relate one experiment which I made with consi-

derable care,—it will show how near the truth I was able to come.

Bihydrate. 1. A quantity of alumina left upon the filter in a temperature not exceeding 60°, for a couple of months, was found to weigh 36·66 grains. Being strongly ignited in a platinum crucible, the weight was reduced to 17·85 grains. The loss of weight, therefore, was 18·81 grains, which gives the amount of the water in the hydrate. Now, 17·85 : 18·81 : : 2·25 : 2·42624, which exceeds 2 atoms of water by 0·17624 ;—and this excess of water I find it difficult to get rid of in a damp room. If we were to consider the water in this hydrate as amounting to exactly 2 atoms, and to calculate the atomic weight of alumina on that supposition, we have 18·81 : 17·85 : : 2·25 : 2·1352 = atomic weight of alumina. But the analysis of alum, given in a preceding part of this section, shows that there is really an excess of water. Besides, I have frequently obtained a hydrate of alumina composed exactly of equal parts of alumina and water, showing that the atomic weight of alumina is exactly 2·25, and that this hydrate contains 2 atoms water.

Hydrate. 2. When the bihydrate of alumina is dried in a temperature of about 100°, it is reduced to the state of a hydrate—at least very nearly, for I have not always been able to obtain exactly the atomic proportions, though the deviation was

small. I shall state one or two of the experiments numerically, that the reader may judge of the approximation.

(1.) 18·92 grains of alumina, dried on the filter in a temperature of 100°, being exposed to a strong red heat, were reduced to 13·49 grains; consequently, the water driven off amounted to 5·43 grains. Now,

13·49 : 5·43 : : 2·25 : 0·9055 = ratio of water.

(2.) 20 grains of alumina, which had been left upon a filter for three months, in a temperature which, during the day, was usually 85°, though during the night it was lower, as the fire was allowed to go out, being exposed to a strong red heat, was reduced to 13·45 grains; and, consequently, it had lost 6·55 grains. Now,

13·45 : 6·55 : : 2·25 : 1·099 = ratio of water.

It appears from this experiment, that by a great length of time the alumina may be brought into the state of a hydrate, consisting of 1 atom alumina and 1 atom water; for 1·099 is only a very little less than 1·125, the weight of an atom of water.

Such are the results which I have obtained respecting the atomic weight of alumina. They all conspire to show that it is very nearly 2·25, and that it cannot by any means amount to a

number nearly so high as 3·375. Indeed, from the constitution of alumina, there seems no reason to doubt that 2·25 is the true atomic weight of this earth.

Atom of aluminum.

The probability is, that alumina is a protoxide of aluminum. On that supposition, the atomic weight of aluminum will be 1·25.

SECT. II.

OF THE ATOMIC WEIGHT OF GLUCINA.

THOUGH glucina has been known to chemists for more than twenty years, we are in possession of very few experiments from which we can deduce its atomic weight. Berzelius, so far as my knowledge extends, is the only person who has analyzed some of the salts of glucina with a view of determining its capacity of saturation, from which the atomic weight is easily deduced. Before relating the experiments which I have made to ascertain the atomic weight of this substance, it will be interesting to state the experiments of Berzelius, by which, in fact, my own were directed.

Analysis of sulphate of glucina by Berzelius.

1. Berzelius dissolved a quantity of glucina in an excess of sulphuric acid—evaporated the solution till the acid began to escape—and then washed it in alcohol to get rid of the excess of

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sulphuric acid. The sulphate of glucina thus obtained was dissolved in water. The solution was mixed with carbonate of ammonia to precipitate the glucina, and heat was applied till the ammonia ceased to be disengaged. The glucina thus obtained, being well washed and heated to redness, weighed 0·553 parts: the liquid thus freed from glucina was precipitated by muriate of barytes. The sulphate of barytes, after being washed and heated to redness, weighed 5, which is equivalent to 1·6949 of sulphuric acid.*

Thus it appears, that the sulphate of glucina, formed by the above process, is composed of

Glucina	0·553	or	3·2627
Sulphuric acid	1·6949	-	10

Considering this salt as a bisulphate, Berzelius dissolved a portion of it in water and digested it over a quantity of carbonate of glucina free from ammonia. By this digestion he obtained a gummy looking liquid. Part of this being mixed with water, a white matter precipitated, (doubtless glucina) and the liquid being filtered, was decomposed by carbonate of ammonia and muriate of barytes precisely as the former salt. The glucina obtained weighed 1·001, and the sulphate of barytes 4·549, equivalent to 1·5573 sulphuric acid. Thus it appears, that the new

* Berzelius' Attempt, &c. p. 134.

gummy like sulphate of glucina was composed of

Glucina	1·001	or	3·2139
Sulphuric acid	1·5573	-	5

A portion of the gummy liquid, obtained as above described, was heated over a spirit lamp till it became dry, when it resembled *burned alum*. After ceasing to give out water from the heat of a spirit lamp, Berzelius exposed 2·5 parts of it to a red heat; the glucina left weighed 1·24 parts. Berzelius, considering the salt as perfectly dry, concludes it was composed of

Glucina	1·24	or	4·92
Sulphuric acid	1·26	-	5
	2·50		

It is obvious that the second of these three salts is neutral, being composed of one atom of acid and one atom of glucina. The first is a bisulphate, or a compound of two atoms acid and one atom glucina, while the third is a sulphate composed of one atom acid, and 1½ atom glucina.

These three analyses, however, are not absolutely correct; for the atomic weight of glucina differs a little in each.

By the first it is		3.2627
second		3·2139
third		3·2800
		3)9·7566
Mean	=	3·2522

This mean of 3·2522 must be exceedingly near the truth; as near, probably, as it is possible to come with our present analytical means by a direct analysis. I consider myself entitled to conclude from it, that the true atomic weight of glucina is 3·25. I leave out the two last decimal places, because they would destroy the law pointed out by Dr. Prout, which we have seen to hold in all the other atomic weights of bodies;—namely, that these weights are all multiples of 0·125, the atomic weight of hydrogen.

2. Berzelius likewise analyzed the muriate of glucina; and, although the muriates are not so easily analyzed with accuracy as the sulphates, it will be well worth our while to state the result of the analysis as constituting an exceedingly good approximation. The bimuriate of glucina was a crystallizable salt: but when the excess of acid was expelled, he obtained only a gummy like mass. This matter was dissolved in water, the solution filtered, and the glucina was thrown down by carbonate of ammonia, and the muriatic acid by nitrate of silver. The glucina weighed 0·626, and the chloride of silver 3·392, which is equivalent to 0·85962 of muriatic acid. According to this analysis, muriate of glucina is composed of

Glucina	0·266	or	3·3681
Muriatic acid	0·85962	-	4·625 *

The atomic weight of glucina deduced from this analysis is 3·3681, which is a little higher than that from the sulphate. But the preponderancy of evidence is entirely in favour of 3·25, the weight deduced from the sulphates of glucina.

Composition of emerald.

3. The *emerald* or *beryl* is the mineral from which glucina was originally obtained, and indeed, we are scarcely in possession of any other quarry from which this earth can even at present be procured. It is usually crystallized in six-sided prisms, and has all the marks of being a chemical compound. Its constituents are silica, alumina, and glucina, with mere traces of some metallic oxides, which seem to act the part of colouring matters. It will be worth our while to see what atomic weight will be deduced for glucina from the constituents of this mineral.

Vauquelin and Klaproth published good analyses of emerald and beryl; but it will be better to employ for our calculations the analysis by Berzelius, which is much later, and which, from the improvements introduced into the art of analyzing minerals, is probably nearest the truth. According to Berzelius, the constituents of this mineral are as follows: †

* Berzelius' Attempt, &c. p. 134. † Afhandlingar, IV. 192.

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Silica .	68·35
Alumina .	17·60
Glucina ·	13·13
Oxide of iron	0·72
Oxide of tantalum	0·27
	100·07

Let us consider the emerald as a compound of two atoms of trisilicate of alumina, and one atom of trisilicate of glucina, and let us see what the quantity of silica will be, supposing the atomic weights of alumina and glucina to be 2·25 and 3·25 respectively.

(1.) 2·25 (atom of alumina) : 6 (3 atoms silica) : : 17·6 (alumina in mineral) : 46·933 = silica united to alumina.

(2.) 3·25 (atom of glucina) : 6 : : 13·13 : 22·422 = silica united to glucina.

Now, 46·933 + 22·422 = 69·355, which exceeds the silica in the mineral by 1·005 grain. The silica united to the alumina is very nearly two-thirds of the whole; consequently, two-thirds of this surplus belongs to that portion of the silica. There remain 0·335 grain, which must be deducted from the 22·422. The remainder, 22·087, is the silica actually united to the glucina in the mineral. Now, 22·087 : 13·13 : : 6 : 3·5668 = atom of glucina.

2. Euclase.

Composition of euclase.

There is another mineral, containing glucina,

namely *euclase*; the constituents of which, according to the analysis of Berzelius, are as follows:

Silica .	43·32
Alumina .	30·56
Glucina .	21·78
Oxide of iron	2·22
Oxide of tin	0·70
	98·58

Let us calculate the constitution of this mineral, on the supposition that it is composed of two atoms silicate of alumina, one atom of silicate of glucina, and a small quantity of bisilicate of iron, probably accidentally present.

(1.) 2·25 : 2 : : 30·56 : 27·164 = silica united to alumina.
(2.) 3·25 : 2 : : 21·78 : 13·403 = silica united to glucina.
(3.) 4·5 : 4 : : 2·22 : 1·973 = silica united to iron.

Now, 27·164 + 13·403 + 1·973 = 42·540, which is less than the silica in the mineral by 0·98 grain. Two thirds of the silica are united to the alumina;—consequently, only one third of 0·98 or 0·33 is to be added to the 13·403, making 13·733 grains for the silica united to the glucina. And

13·733 : 21·78 : : 2 : 3·1719 = atomic weight of glucina.

From these two minerals we obtain two different atomic weights of glucina, the first too high, and the second too low. The probability

is, that the mean of the two will give an atomic weight not very far removed from the truth.

Atomic weight from beryl	3·5668
euclase	3·1719
	2)6·7387
Mean . . =	3·36935

This result, though too high, is much nearer the truth than that derived from the analysis of beryl alone.

Analysis of bisulphate of glucina by the author.

4. I shall now relate the experiments by which I satisfied myself that 3·25 is the exact atomic weight of glucina.

(1.) I prepared a quantity of bisulphate of glucina precisely in the same way as had been previously done by Berzelius: 18·875 grains of this salt were put into a platinum crucible, and exposed for some time to a strong red heat:—there remained 3·25 grains of pure glucina.

(2.) 18·875 grains of the same salt, and 26·5 grains of chloride of barium, were dissolved in separate portions of distilled water. These two liquids being mixed, a double decomposition took place—sulphate of barytes falling to the bottom, while muriate of glucina remained in solution. This liquid, as soon as it had become transparent, was tested by sulphate of soda and muriate of barytes; but was not affected by either of these reagents, showing that it contained no sensible

quantity either of barytes or sulphuric acid. From this experiment, we see that the quantity of sulphuric acid in 18·875 grains of bisulphate of glucina just saturates the barytes from 26·5 grains of chloride of barium; and consequently, amounts to exactly 10 grains.

(3.) Thus it appears, that 18·875 grains of bisulphate of glucina contain 3·25 grains of glucina and 10 grains of sulphuric acid;—the rest must be water: consequently, the constituents of the salt are

Sulphuric acid	10
Glucina . .	3·25
Water . .	5·625
	18·875

Now, 10 is equivalent to 2 atoms of sulphuric acid, and 5·625 to 5 atoms of water. And comparing this analysis with those of Berzelius, no doubt can remain that 3·25 represents the weight of an atom of glucina.

Atom of glucina.

Atom of glucinum.

We have no data to determine the atomic weight of glucinum. But analogy leads to the supposition, that glucina is a compound of 1 atom glucinum and 1 atom oxygen—on that supposition an atom of glucinum will weigh 2·25.

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SECT. III.

OF THE ATOMIC WEIGHT OF YTTRIA.

Though yttria has been known for almost twenty years, the minerals in which it occurs have been hitherto met with only in Sweden; and even in that country, they are so scarce as hardly to be procured, except in pieces too small to admit of the extraction of a quantity of yttria sufficiently large to enable us to make experiments on the composition of the salts which it forms. Thus circumstanced, I have been necessarily confined to experiments made upon a very few grains of this earth; and though they were conducted with the most scrupulous attention to accuracy, I was not able to draw any satisfactory conclusions from them. I am, therefore, under the necessity of deducing the atomic weight of this earth from the experiments of Berzelius. Fortunately, this illustrious chemist is so remarkably accurate in his experiments, that they are sure to furnish an exceedingly good approximation.

Analysis of carbonate of yttria.

1. Berzelius put 100 parts of dry carbonate of yttria into a small retort, a glass tube connected with the beak of which, was filled with dry mu-

riate of lime. Heat was applied and continued till the retort began to soften. By this process the water was driven off and united to the muriate of lime, the weight of which it had increased by 12·82 parts. The yttria, thus freed from water, was heated to redness in a platinum crucible, in order to drive off the carbonic acid:—by this process its weight was reduced to 57·7 parts. From this analysis, it appears that carbonate of yttria is composed of

Carbonic acid	29·48	or	2·75
Yttria .	57·70	-	5·3825
Water .	12·82	-	1·1959
	100·00*		

This analysis gives us 5·3825 for the atomic weight of yttria. But the water in the salt, which obviously ought to amount to 1 atom, is a little too high. The probability is, that the water absorbed by the muriate of lime would retain a little carbonic acid. If we divide the 42·3 parts which make up the carbonic acid and water in the ratio of 2·75 : 1·125—which must have been the true proportion of those bodies, on the supposition that the salt was a chemical compound,—we shall have the constituents of this carbonate as follows:

* Annals of Philosophy, III 359.

Carbonic acid	30·019	or	2·75
Yttria .	57·700	-	5·285
Water .	12·281	-	1·125
	100·000		

This brings the atomic weight of yttria to 5·285, a number which must come pretty near the truth.

Of sulphate of yttria.

2. Berzelius dissolved 2·8 parts of pure yttria in sulphuric acid—evaporated the solution to dryness—and heated the residual sulphate till it ceased to give out acid vapours. It now weighed 5·392 parts. From this experiment he concluded, that anhydrous sulphate of yttria is composed of

Sulphuric acid	2·592	or	5
Yttria . .	2·8	-	5·4012
	5·392*		

By this experiment the atomic weight of yttria comes out 5·4012. But we have no satisfactory evidence that the salt was neutral, except that it was still soluble in water. I am disposed to think that a very small portion of the acid had been driven off: for if we suppose the constituents of the salt to have been

Sulphuric acid	2·685
Yttria . .	2·8
	5·485

* Annals of Philosophy, III. 359.

—that is to say, had the acid been 0·093 more, then the atomic weight of yttria would have been 5·25.

Of hydrate of yttria.

3. Klaproth found that yttria precipitated from muriatic acid, and dried in the open air after being well washed, was a hydrate composed of

Yttria . . .	69
Water . . .	31
	100

For 100 parts of it when heated to redness lost 31 parts of its weight. Now, 31 : 69 : : 2·25 : 5·008 = atomic weight of yttria, supposing the hydrate to contain just 2 atoms water.

Thus we have got three atomic weights of yttria.

(1.) From the carbonate . .	5·285
(2.) From the sulphate . .	5·4012
(3.) From the hydrate . .	5·008
	3) 15·6942
Mean	5·2314

This mean must be very near the truth: we may, therefore, adopt 5·25 as the true atomic weight of yttria in order to make that weight accord with Dr. Prout's law.

Analysis of gadolinite.

4. Gadolinite, the mineral in which yttria was first discovered, has been likewise analyzed with

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great care by Berzelius, who found its constituents as follows:

Silica . .	25·80
Yttria . .	45·00
Protoxide of cerium	16·69
Protoxide of iron	10·26
Volatile matter	0·60
	98·35 *

Let us calculate the composition of this mineral, on the supposition that the yttria and oxides of cerium and iron are respectively in the state of silicates, and that the atomic weights of all of these constituents are as follows:

Silica . .	2
Yttria . .	5·25
Protoxide of cerium	7·25
Protoxide of iron	4·5

(1.) 5·25 (atom of yttria) : 2 (atom of silica) : : 45 (yttria in the mineral) : 17·14 = silica united to yttria.

(2.) 7·25 (atom protoxide of cerium) : 2 : ; 16·69 : 4·302 = silica united to the oxide of cerium.

(3.) 4·5 (atom of oxide of iron) : 2 : : 10·26 : 4·56 = silica united to the oxide of iron.

Now, 17·14 + 4·302 + 4·56 = 26·002, which exceeds the silica found in the mineral by 0·2002 grain.

The silica united to the oxides of cerium and iron being one third of the whole, it is ob-

* Afhandlingar, IV. 225.

vious, that one third of this surplus, or 0·0667 belongs to that portion; we have, therefore, 0·1335 grain to subtract from the 17·14, to obtain the quantity of silica in the mineral, actually united to the yttria. It amounts to 17·0065. And

17·0065 : 45 : : 2 : 5·2921 = atomic weight of yttria.

Of yttrocerite.

5. There is another mineral, which was discovered by Berzelius at Finbo in Sweden, and analyzed with great care, namely, the yttrocerite, which he found composed as follows:

Lime . .	50
Yttria . .	8·1
Protoxide of cerium	16·45
Fluoric acid	25·45
	100·00*

Let us suppose the lime and yttria in this mineral to be in the state of neutral fluates, and protoxide of cerium in the state of a bifluate, and let us calculate the composition, on the supposition that the atom of fluoric acid is 1·25, which will be proved in a subsequent chapter.

(1.) 3·5 (atom of lime) : 1·25 (atom of fluoric acid) : : 50 (lime in the mineral) : 17·857 = fluoric acid united to lime.

(2.) 5·25 (atom of yttria) : 1·25 : : 8·1 : 1·928 = fluoric acid united to yttria.

(3.) 7·25 (atom of oxide of cerium) : 2·5 (2 atoms fluoric acid) : : 16·45 : 5·672 = fluoric acid united to oxide of cerium.

* Afhandlingar, IV. 151.

Now, 17·857 + 1·928 + 5·672 = 25·457, which exceeds the fluoric acid found in the mineral by 0·007 grain. But $\frac{22}{100}$ part of the fluoric acid are united to the lime and the cerium, so that only $\frac{8}{100}$ of 0·007 or 0·00056 grain require to be subtracted from 1·928, to have the fluoric acid actually united to the yttria, according to the analysis. This amounts to 1·9224. And

1·9224 : 8·1 : : 1·25 : 5·2668 = an atom of yttria.

6. There is still another mineral, namely, the yttrotantalite, which appears to consist essentially of oxide of tantalum and yttria united together. But the other constituents vary so much, that no greatreliance can be put on the analyses hitherto given, the specimens appearing all exceedingly impure. There are three varieties, which differ a good deal from each other in the proportions of their constituents. The first variety has a black colour, and was found by Berzelius composed of Yttrotantalite.

Oxide of tantalum	57
Tungstic acid .	8·25
Yttria . .	20·25
Lime . . .	6·25
Oxide of iron .	3·50
Oxide of uranium	0·50
	95·75 *

* Afhandlingar. IV. 267.

The second variety, which is yellow, was composed of

Oxide of tantalum	60·124
Tungstic acid .	1·044
Yttria . .	29·780
Lime . .	0·500
Oxide of iron .	1·155
Oxide of uranium	6·622
	99·225

The third variety, which is dark brown, was composed of

Oxide of tantalum	51·815
Tungstic acid .	2·592
Yttria . .	38·515
Lime . . .	3·260
Oxide of iron .	0·555
Oxide of uranium	1·111
	97·848

It must be obvious from a bare inspection of these three analyses, that the ratios between the oxide of tantalum and the yttria differ too much in each, to enable us to deduce from them any information, either respecting the atomic weights of yttria or oxide of tantalum;—not to mention the tungstic acid, the lime and the oxide of uranium, which are still more variable. But a comparison of the atomic weight of yttria, deduced from the analyses of gadolinite and yttrocerite, with the weights deduced from the car-

bonate, sulphate and hydrate of yttria, leave little doubt that the true atomic weight of this earth is 5·25. Atom of yttria.

Analogy is in favour of the notion, that yttria is a compound of one atom of yttrium and one atom of oxygen; on that supposition, the atomic weight of yttrium will be 4·25. Of yttrium.

SECT. IV.

OF THE ATOMIC WEIGHT OF ZIRCONIA.

We have no good data for calculating the atomic weight of zirconia. The best at present in our possession, are derived from the composition of the zircan and hyacinth, which have been repeatedly analyzed by Klaproth and Vauquelin. The constituents of this mineral, as deduced from their analyses, are as follows:

Analyses of zircon.

Zirconia	69·0	65	64·5	70	64·5	66
Silica	26·5	33	32·5	25	32	31
Oxide of iron	0·5	1	1·5	0·5	2	2
	96·0 *	99 †	98·5 ‡	95·5 §	98·5 ‖	99 ¶

The great difference in these results renders it probable that none of the analyses is quite cor-

* Klaproth Bectrage, I. 222. † Ibid. III. 271. From Norway.
‡ Ibid. V. 130. From the Circars. § Ibid. I. 231. From Ceylon.
‖ Vauquelin, Jour. de Min. No. XXVI. 106. ¶ Vauquelin, Ibid.

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rect. Indeed, neither Klaproth nor Vauquelin succeeded in freeing the zirconia completely from iron. But if we deduce the atomic weight of zirconia from these analyses, supposing the minerals to be simple silicates of zirconia mixed with a little silicate of iron, then the atomic weight of zirconia will be as follows:

From first analysis	5·247
From second	3·987
From third	4·043
From fourth	5·645
From fifth	4·134
From sixth	4·370
	6)27·426
Mean - -	4·537

A careful examination of a collection of hyacinth crystals, which I was favoured with some years ago by Mr. Heuland, serves, in some measure, to explain the reason of these anomalies. Besides crystals of zircon, I found among them likewise crystals of spinell, garnet, quartz, and some green fragments having the colour of emerald,—besides some black grains, apparently octohedral iron ore. It was doubtless owing to the presence of some of these foreign crystals that the alumina, which I observed in a former analysis of the hyacinth, is to be ascribed. Pure and regular crystals of hyacinth seem composed of

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Zirconia . . .	75
Silica . . .	25
Oxide of iron . .	0·5
	100·5

If we suppose the iron foreign, and the mineral a simple silicate, then the atomic weight of zirconia would be 6, which, from experiments immediately to be mentioned, I believe to be its true weight.

Composition of eudialite.

There is another mineral containing zirconia, which was discovered by Sir Charles Giesecke, at Kangerdluarsuk in Greenland; and to which Professor Stromeyer, to whom we are indebted for a knowledge of its composition, gave the name of eudialite. It was found by Giesecke on the west coast of Greenland, in the same bed that contains the sodalite, and intimately mixed with that mineral and with hornblende. It is sometimes amorphous, and sometimes crystallized in rhomboidal octahedrons, with their edges truncated: it has a rose red, or rather a hyacinth red colour: it is hard enough to scratch glass, but is easily scratched by pyrope: it is easily reduced to powder, and the powder has a red colour: the specific gravity is 2·90355, according to Stromeyer: it is, therefore, considerably lighter than the pyrope, to which it bears a certain degree of resemblance. The specimen of this mineral in my possession, and for which I am indebted to the liberality of Sir Charles Giesecke,

exhibits a tendency to split into rhomboidal fragments:—the fracture is flat, conchoidal, and slightly splintery. Before the blow pipe it melts easily into a green coloured bead: it dissolves with great facility in nitric or muriatic acids, and gelatinizes like mesotype or apophyllite. This solution and gelatinization takes place even when the eudialite has been previously heated to redness. The constituents of this mineral, from a mean of several careful analyses of it by Stromeyer, are as follows:*

Silica . . .	53·325
Zirconia . . .	11·102
Lime . . .	9·785
Soda . . .	13·822
Protoxide of iron .	6·754
Protoxide of manganese	2·062
Muriatic acid . .	1·034
Water . . .	1·801
	99·685

The great number of constituents in this mineral renders it very ill adapted for determining the atomic weight of zirconia. Let us suppose that the muriatic acid is in combination with soda in the mineral:—it will constitute 1·676 parts of common salt, and the remaining soda will amount to 13·13. Let us now calculate the composition of eudialyte, on the supposition that all the bases

* Untersuchungen, I. p. 438.

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are combined with silica in the state of trisilicates, except the soda, which must be in the state of bisilicate; and let us consider the atomic weight of zirconia as 6, that of lime as 3·5, that of soda as 4, and that of protoxide of iron and manganese as 4·5.

(1.) 6 (atom of zirconia) : 6 (3 atoms silica) : : 11·102 : 11·102 = silica united to the zirconia.

(2.) 3·5 (atom of lime) : 6 (3 atoms silica) : : 9·785 : 16·77 = silica united to the lime.

(3.) 4 (atom of soda) : 4 (2 atoms silica) : : 13·13 : 13·13 = silica united to the soda.

(4.) 4·5 (atom of protoxide) : 6 (3 atoms silica) : : 8·816 : 11·75 = silica united to the protoxide of iron and manganese.

Now, 11·102 + 16·77 + 13·13 + 11·75 = 52·752. This is less than the whole silica in the mineral by 0·573. As the silica in combination with the zirconia constitutes $\frac{1}{48}$ of the whole, it is obvious, that, in order to have the quantity of silica united to the zirconia in the eudialite, we must add $\frac{1}{48}$ of 0·573 = 0·12 to 11·102, which will raise it to 11·222. This gives us

11·222 : 11·102 : : 6 : 5·9358 = atomic weight of zirconia,

according to the constitution of this mineral. Though this number be under 6, yet it approaches fully as near it as could be expected from so complicated a mineral; which, probably, was not free from some admixture both of sodalite and hornblende.

I shall now relate the experiments which I made to determine the saturating power of zirconia, and the quantity of water with which it is capable of combining.

Hydrates give the atom of zirconia = 6.

(1.) A quantity of pure carbonate of zirconia was dissolved in muriatic acid, the solution was precipitated by ammonia, and the earth, after being well washed, was left for several weeks upon the filter in a temperature, which, during the day, was very nearly 85°; though it was a good deal lower during the night. The hydrate thus obtained had a greyish yellow colour, a certain degree of semitransparency, and broke with a fracture resembling that of glue. It was exposed to a strong red heat for nearly an hour, in order to drive off the water. I found that this hydrate was a compound of

Zirconia . . .	6
Water . . .	8·885

Now, 8·885 differs very little from 9, which represents the weight of 8 atoms of water. This leads to the inference, that the atomic weight of zirconia is 6, and that the hydrate was a compound of 1 atom zirconia and 8 atoms water.

(2.) Another quantity of zirconia, precipitated from the muriate, was well edulcorated and dried on the filter by means of steam, at the temperature of 212°. The hydrate thus obtained was decomposed in a strong red heat, and was found to be composed of

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Zirconia	.	.	6
Water	.	.	1·125

Now, 1·125 represents an atom of water. Hence, the hydrate was a compound of 1 atom zirconia and 1 atom water; and this experiment also leadst o the conclusion that an atom of zirconia weighs 6.

Muriate of zirconia.

(3.) 11·85 grains of pure muriate of zirconia, not in crystals, but formed by dissolving zirconia in muriatic acid, and evaporating the solution to dryness in a low temperature, were dissolved in water, and the zirconia thrown down by ammonia. When properly washed and dried, and heated to redness, it weighed 4·331 grains. The liquid thus freed from zirconia, was neutralized by nitric acid, and the muriatic acid thrown down by nitrate of silver. The chloride of silver, after fusion, weighed 13·59 grains, equivalent to 3·444 grains of muriatic acid. From this experiment it follows, that muriate of zirconia is composed of

Muriatic acid	3·444	or	4·625
Zirconia .	4·331	-	5·815
Water .	4·075	-	5·437

4·625 denotes the weight of an atom of muriatic acid—5·437 approaches pretty near to 5·625, the weight of 5 atoms of water—5·815 represents the atomic weight of zirconia, according to this experiment:—it is a little less than 6, the atomic weight deduced from the hydrates. I

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am disposed to ascribe this to a slight excess of muriatic acid in the salt. My quantity of zirconia was not sufficient to give me muriate of zirconia in crystals.

These experiments are not quite decisive; but they lead to the conclusion, that the atomic weight of zirconia is 6.

CHAP. X.

OF THE ATOMIC WEIGHTS OF IRON, NICKEL, COBALT, MANGANESE, AND CERIUM.

These metals are very nearly related to each other, both in their atomic weights and in the proportions of oxygen with which they combine. Each of them forms at least two oxides, the first containing an atom of oxygen, and the second an atom and a half of oxygen united to an atom of the metal; and both of these oxides, at least in the case of iron and manganese, is capable of combining with acids. One of these metals, I mean manganese, unites with two, if not three, additional dozes of oxygen, forming an oxide neither possessing alkaline nor acid properties, and one or two oxides capable of combining with bases, and consequently, possessing the characters of acids.

SECT. I.

OF THE ATOMIC WEIGHT OF IRON.

Analysis of protosulphate of iron.

Protosulphate of iron, or *green vitriol*, is a salt which has been long known, and manufac-

tured for the use of dyers and other artists. It crystallizes in four-sided oblique prisms with a rhombic base, is transparent, has a light green colour, and a sweetish astringent taste. It may be obtained perfectly pure from the copperas manufactories; or by dissolving the salt of commerce in boiling water, filtering the solution while hot, and allowing it to crystallize by cooling. I employed this salt to determine the atomic weight of protoxide of iron, and I shall now state the method by which I proceeded.

1. 17·375 grains of pure dry crystals of protosulphate of iron were dissolved in water, and mixed with a solution of 13·25 grains of chloride of barium. A double decomposition immediately took place, and sulphate of barytes precipitated to the bottom of the vessel. When the liquid had become clear after the subsidence of this sulphate, it was tested by means of sulphate of soda, and muriate of barytes; but was not affected by either of these reagents, showing that it neither contained barytes nor sulphuric acid. From this experiment it is evident, that the barytes from 13·25 grains of chloride of barium, just saturates the sulphuric acid in 17·375 grains of crystallized protosulphate of iron. Consequently, 17·375 grains of protosulphate of iron contain exactly 5 grains of sulphuric acid.

2. 17·375 grains of crystallized protosulphate of iron were exposed for some time in a plati-

num crucible to a heat of between 500° and 600°. The loss of weight was 7·6 grains.

Now, as 17·375 grains of this salt contain just 5 grains of sulphuric acid, which is equivalent to the weight of an atom, the water of crystallization ought likewise to be a determinate number of atoms. Now, 7·875 grains would be equivalent to 7 atoms. And the water actually found was 7·6 grains, which is only 0·275 grains, or $\frac{1}{4}$th of an atom less than 7 atoms.

But all the water cannot be separated from this salt by heat, without at the same time decomposing and separating a portion of the sulphuric acid. Sulphurous acid begins to be disengaged, and sulphuric acid in a liquid state (and therefore containing water) trickles down the sides of the retort.

It is easy to show that the water which remains behind, and which comes over united to the sulphuric acid, is exactly $\frac{1}{4}$th of an atom. For the sake of explanation, I shall take for granted what will be proved in the subsequent part of this section; namely, that an atom of iron weighs 3·5, an atom of protoxide of iron 4·5, and an atom of peroxide of iron 5.

When protosulphate of iron, freed from as much water of crystallization as possible, is strongly heated, the protoxide of iron which it contains is converted into peroxide at the expense of the sulphuric acid, which gives off one

atom of oxygen to the iron, and then flies off in the state of sulphurous acid. Now, 1 atom of oxygen will convert 2 atoms of protoxide of iron into peroxide. It is obvious from this, that one half of the sulphuric acid is decomposed, and that the other passes over in the state of fuming sulphuric acid. Now, this fuming acid I have carefully analyzed, and I find it a compound of

2 atoms sulphuric acid	=	10
1 atom water	=	1·125
		11·125

Let us suppose that a quantity of protosulphate of iron, equivalent to 4 integrant particles, or 69·5 grains (17·375 × 4) of the crystals, are treated in this way. By exposing them to a heat of about 600°, they lose 30·375 grains, or the whole of the water, except one atom. There remain 39·125 grains, composed of

4 atoms sulphuric acid	=	20
4 atoms protoxide of iron	=	18
1 atom of water	=	1·125
		39·125

When a strong heat is applied to this residuum, half the sulphuric acid, or 10 grains, is decomposed into

2 atoms of sulphurous acid	=	8
2 atoms of oxygen	=	2
		10

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The 8 grains of sulphurous acid fly off in the state of gas, and the 2 grains of oxygen unite with the 18 grains of protoxide of iron, and convert them into 20 grains of peroxide. The remaining 10 grains of sulphuric acid, united to the atom of water, are driven off in the state of fuming sulphuric acid, and weighing 11·125 grains.

From this statement it is obvious, that when 17·375 grains of protosulphate of iron are thus treated, 7·59375 grains of water (or 7 atoms — ¼th atom) will be driven off; 2½ grains of sulphuric acid will be converted into 2 grains of sulphurous acid (which will fly off) and half a grain of oxygen, which will convert the 4½ grains of protoxide into 5 grains of peroxide. The remaining 2½ grains of sulphuric acid united with 0·28125 grains of water, (the ¼th atom still remaining) will be driven off in the state of fuming sulphuric acid.

From the preceding exposition it is plain, that after all the water has been driven off, which can be made to leave 17·375 grains of protosulphate of iron by a moderate heat, one fourth of an atom, or 0·28125 grain still remains. Hence, the whole water of crystallization amounts to 7·6 + 0·28125 = 7·88125 grains. This comes so near 7·875 grains, which is the equivalent of 7 atoms, that there can be no doubt that 7 atoms is the true quantity of water present. The small excess (only 0·00625 grain) was owing to a com-

mencement of decomposition, for the whole of the salt thus treated was not soluble in water.

Thus it appears that 17·375 grains of protosulphate of iron contain

1 atom sulphuric acid	= 5
7 atoms water .	= 7·875
	12·875

Atom of protoxide of iron = 4·5.

The 4·5 grains, wanting to make up the whole 17·375, are obviously protoxide of iron; and, as the salt is neutral, 4·5 must denote the atomic weight of protoxide of iron.

3. The preceding analysis of protosulphate of iron is rigidly exact; but it proceeds upon assumptions which require to be proved. It will now be requisite to state the experiments by which I satisfied myself that 3·5 is the true atomic weight of iron.

Atomic weight of iron determined.

35 grains of pure iron were put into a small retort, with dilute sulphuric acid. A complete solution took place; and the volume of the hydrogen gas evolved (reduced to the mean temperature and pressure) was 59 cubic inches. Consequently, the iron must have combined with a quantity of oxygen, which, had it been in the gaseous state, would have amounted to $\frac{59}{2}$, or 29·5 cubic inches, which weigh almost exactly 10 grains. From this it is obvious, that when 3·5 grains of pure iron are dissolved in dilute sul-

phuric acid, they combine with 1 grain of oxygen. Now, by this solution, the iron is converted into protoxide; consequently, protoxide of iron is composed of

Iron	.	3·5
Oxygen	.	1
		4·5

1 being the atomic weight of an atom of oxygen, 3·5 must be the weight of an atom of iron; and the atomic weight of protoxide of iron is obviously 4·5.

Sulphuret of iron analyzed.

4. Iron and sulphur unite together in two proportions, forming the *protosulphuret* and *persulphuret* of iron. The former is called by mineralogists *magnetic pyrites*, because, when in powder, it is attracted by the magnet. The latter is called *cubic pyrites*, because it usually crystallizes in cubes. The protosulphuret of iron may be formed artificially, by mixing together iron filings and sulphur, and exposing the mixture for some time to a red heat, in a well covered crucible. The mixture fuses, and the excess of sulphur is gradually driven off, and protosulphuret of iron remains. This sulphuret, when in crystals, has a yellow colour, the metallic lustre, and a specific gravity of about 4½.

When it is reduced to powder, and digested for a sufficient length of time in nitric acid, the

sulphur is converted into sulphuric acid, while the iron at the same time is oxydized. If the solution, thus changed, be mixed with a sufficient quantity of muriate of barytes, sulphate of barytes precipitates, the weight of which enables us to determine the proportion of sulphur which the protosulphuret of iron contains. 100 grains of protosulphuret, treated in this way by Berzelius, yielded him 269 grains of sulphate of barytes.* This weight exceeds the truth a little; because a portion of the oxide of iron is precipitated along with the sulphate of barytes, sufficient to give it a reddish yellow colour. When the oxide of iron is precipitated, in the first place, by means of ammonia, and the requisite precautions taken to prevent any of the sulphuric acid from remaining in combination with this precipitate, the sulphate of barytes is perfectly white, and weighs almost exactly 267·37 grains. Now, 267·37 grains of sulphate of barytes contain almost exactly 36·36 grains of sulphur. Thus it appears that 100 grains of protosulphuret of iron contain 36·36 grains of sulphur. Consequently, the constituents of the protosulphuret are

Sulphur	36·36	or	2
Iron .	63·64	-	3·5002
	100·00		

It is obvious that this protosulphuret is a com-

* Ann. de Chim. LXXVIII. 126.

pound of 1 atom sulphur and 1 atom iron; and, consequently, that an atom of iron weighs 3·5. These observations apply only to protosulphuret of iron formed artificially. The native protosulphuret, when dissolved in muriatic acid, always deposites a little sulphur. Hence, it contains either a small mixture of persulphuret of iron or of sulphur.

May be converted into protosulphate of iron.

Now, it is possible to convert protosulphuret of iron into neutral protosulphate of iron, by careful digestion in a sufficient quantity of dilute nitric acid. Hence it follows, that the sulphur and iron have the same ratio to each other in protosulphuret and protosulphate of iron; namely, the ratio of 2 to 3·5. When 2 of sulphur are converted into sulphuric acid, they become 5; and when 3·5 of iron are converted into protoxide, they become 4·5, as is obvious from what has been stated above. Hence it is clear, that 17·375 grains of protosulphate of iron must contain exactly 4·5 grains of protoxide of iron; as the quantity of sulphuric acid has been shown to be 5 grains. Thus the proportion of acid, oxide, and water in 17·375 grains of protosulphate of iron has been rigidly made out; and the component parts of the salt are as follows:

1 atom sulphuric acid	5
1 atom protoxide of iron	4·5
7 atoms water .	7·875
	17·375

Experiments of Berzelius to determine the atom of iron.

5. Berzelius has fixed the atomic weight of iron at 3·39215, or (as the number should have been) 3·393. His conclusion is founded upon the following experiment: 100 grains of iron were dissolved in muriatic acid, and the hydrogen gas evolved being burned over lime water, a quantity of carbonate of lime precipitated, which weighed 4·125 grains. Now, this is equivalent to 0·495, or very nearly half a per cent. of carbon. The solution was boiled with nitric acid, to peroxidize the iron; it was then precipitated by caustic ammonia. The precipitate, being washed, dried, and calcined, weighed 143·5 grains; but, if 99·5 grains of iron yielded 143·5 grains, it is evident that 100 grains would have yielded 144·2 grains.* Thus it follows, that peroxide of iron is a compound of

Iron	100	or	3·393
Oxygen	44·2	-	1·5

But this experiment does not seem susceptible of complete accuracy, unless it were made upon iron in a state of perfect purity; for we are not certain that all the carbon is converted into carburetted hydrogen gas. The strong smell of the gas evolved indicates the presence of some oily or bituminous substance, which may be partly deposited before the combustion of the hydrogen gas. Besides, different experimenters have ob-

* Ann. de Chim. LXXVIII. 230.

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tained different results in this way. I made two experiments with great care. In one, 100 iron were converted into 142·6 of peroxide; in another, into 144·75 grains.*

Hassenfratz found that 100 grains of iron, calcined on a cupel, were converted into 142·224 grains of peroxide.† In another experiment, 100 iron, when thus treated, became 145 peroxide.

Bucholz, by an experiment similar to that of Berzelius, obtained 142 grains of peroxide from 100 grains of iron.‡

Gay-Lussac, from 100 grains of iron, obtained 142·35 grains of peroxide.§

The mean of all these experiments gives 43·303 for the quantity of oxygen which unites with 100 of iron. Hence, peroxide of iron according to these experiments is composed of

Iron	100	or	3·463
Oxygen	43·303	-	1·5

Now, 3·463, the atomic weight of iron deduced from these experiments, approaches nearer to 3·5, the weight deduced from the experiments above described, than to Berzelius' number.

6. I determined the atomic weight of the peroxide of iron in the following manner: 7·5 grains of cubic pyrites, very carefully selected, Atom of peroxide of iron determined.

* Nicholson's Journal, XXVII. 378. † Ibid. XXVI. 149.
‡ Ibid. XXV. 353. § Ann. de Chim. III. 356.

were reduced to a coarse powder, and digested in dilute nitric acid till the whole was dissolved. An excess of caustic ammonia was then poured into the solution, by which the peroxide of iron was thrown down. It was collected on a double filter, washed, dried, and exposed to a red heat. It weighed exactly 5 grains. The residual liquid, thus freed from iron, was concentrated, in order to drive off the excess of ammonia. It was then mixed with a sufficient quantity of muriate of barytes to throw down all the sulphuric acid. The sulphate of barytes, thus obtained, being washed, dried, and heated to redness, weighed 29·5 grains, equivalent to 4 grains of sulphur. From this experiment it is evident, that persulphuret of iron is composed of

Sulphur	4
Iron	3·5
	7·5

or two atoms sulphur and 1 atom iron. But during the experiment the 3·5 of iron were converted into peroxide, which weighed 5. Hence it is obvious, that peroxide of iron is composed of

Iron	3·5	or	1 atom
Oxygen	1·5	-	1½ atom
	5		

Consequently, when 100 parts of pure iron are converted into peroxide they become 142·857.

7. Peroxide of iron has the property of combining with water, and forming with it a perhydrate. This compound is found native, and constitutes what the Germans call *brauneisenstein*. D'Aubuisson first showed it to be a perhydrate of iron. Very frequently it is mixed with a little oxide of manganese and silica. This is almost always the case with the variety called hematite. But when the perhydrate is pure, it is a compound of

1 atom water .	1·125
1 atom peroxide of iron	5
	6·125

A portion of this water is very easily dissipated: hence, unless very carefully examined, the portion of water will turn out rather less than an atom.

8. I found, many years ago, that when 100 parts of iron are oxydized by passing the steam of water over them at a red heat, they combine with 29·7528 parts of oxygen.* Bucholz analyzed iron by the same process, and found that 100 grains of the oxide thus obtained, when converted into peroxide by nitric acid, became 110 grains. Hence, he inferred that 100 oxy-

Ferroso-ferric oxide of Gay-Lussac

* Nicholson's Jour. XXVII. 378.

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dized by steam, combine with 29·87 grains of oxygen.* This is nearly the same result as I obtained. But from the subsequent experiments of Gay-Lussac it would appear that iron, oxydized in this manner, unites with more oxygen than was found either by Bucholz or myself. He found the oxide composed† of

Iron	100	or	3·5
Oxygen	37·8	-	1·323

Now, 1·323 is very nearly $1\frac{1}{3}$ oxygen. Hence, it would appear that this supposed oxide is a compound of 1 atom iron + $1\frac{1}{3}$ atom oxygen. Now, this is just the proportion of oxygen which would result from the combination of 1 integrant particle of protoxide, and 2 integrant particles of peroxide of iron; for

1 atom protoxide is composed of	3·5 iron	+	1 oxygen
2 atoms peroxide of . .	7	+	3
Total . . .	10·5		4

And $\frac{10\cdot5}{3} = 3\cdot5$; and $\frac{4}{3} = 1\frac{1}{3}$. So that such a compound would obviously consist of 1 atom of iron, and $1\frac{1}{3}$ atom oxygen.

When this oxide of Gay-Lussac is dissolved in sulphuric acid, and alcohol poured upon the sulphate, a solution of persulphate of iron is ob-

* Nicholson's Jour. XXV. 353. † Ann. de Chim. LXXX. 164.

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tained, while protosulphate remains undissolved. From this and several other facts stated by Gay-Lussac in his Memoir, it is evident that this substance cannot be considered as a peculiar oxide, but as a combination of protoxide, and peroxide in the proportions above stated.

Seems to exist in Prussian blue.

From the phenomena which appear during the manufacture of Prussian blue, there are strong reasons for considering the iron which that pigment contains as in the state of Gay-Lussac's oxide, or as a mixture or compound of 1 part of protoxide with 2 parts of peroxide. For if we attempt to make Prussian blue by means of persulphate of iron at once, we get a pigment apparently of the finest colour; but so intense that it appears quite black when dry. The manufacturers always find it necessary to employ protosulphate of iron. The Prussian blue, when first thrown down, is an exceedingly light blue powder. This powder is continually washed with water for a fortnight or three weeks. The shade gradually deepens during the washings, and when it is judged sufficiently deep, the water is drained off and the pigment allowed to dry.—From my knowledge of this process, I am disposed to think that protoxide and peroxide of iron are capable of uniting in the proportion of 1 atom of the former to 2 atoms of the latter. But, with the exception of Prussian blue, I am not aware of any combina-

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tion into which this compound is capable of entering.

SECT. II.

OF THE ATOMIC WEIGHT OF NICKEL.

THE atomic weight of nickel and its protoxide may be determined without much difficulty from the sulphate, which I find to be a compound of 1 integrant particle of sulphuric acid, 1 integrant particle of protoxide of nickel, and 7 integrant particles of water. This salt has a fine grass green colour, and crystallizes in four-sided rectangular prisms. Its taste is astringent, but not strong, and it is very soluble in water.

Sulphate of nickel analyzed.

1. 17·125 grains of the crystals of this salt were dissolved in water, and mixed with a solution of 13·25 grains of chloride of barium. A double decomposition took place, and sulphate of barytes precipitated. The clear residual liquor being tested by sulphate of soda and muriate of barytes, was not affected by either, showing that it contained neither barytes nor sulphuric acid. It is obvious from this experiment, that 17·125 grains of crystallized sulphate of nickel contain just the quantity of sulphuric acid necessary to saturate the barytes from 13·25 grains of chloride of barium; that is to say, exactly 5 grains of this acid.

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2. When 17·125 grains of crystallized sulphate of nickel are exposed to a heat of 600° for half an hour, they lose 6·25 grains of their weight, or rather more than 5½ atoms of water. But at this temperature the salt does not lose its green colour, and consequently, still retains water. When 17·125 grains of the salt are exposed to a low red heat, they lose their green colour, and in general, diminish in weight 8 grains. But the salt which has been thus treated, is not completely soluble in water, though very nearly so: hence, a small portion of its acid has been disengaged. From this experiment, which I have often made, it appears that the water of crystallization in 17·125 grains of sulphate of nickel is not quite so high as 8 grains. In one experiment in which the heat was applied with much caution, the loss of weight was 7·8 grains, and the salt was completely soluble in water. It is obvious from this, that the water of crystallization in 17·125 grains of sulphate of nickel lies between 7·8 and 8 grains. Now, 7·875 grains of water are equivalent to 7 atoms of that liquid: and as the quantity of acid in this weight of salt is just 5 grains, equivalent to an atom, we can have no doubt that the true quantiy of water is likewise equivalent to 7 atoms, or 7·875 grains.

Five acid and 7·875 water, make 12·875, which being subtracted from 17·125 leaves 4·25, which must be the weight of protoxide of nickel, and

Atom of protoxide of nickel.

must likewise (since the salt is neutral) indicate the atomic weight of protoxide of nickel. Thus it appears, that sulphate of nickel is composed of

1 atom sulphuric acid	5
1 atom protoxide of nickel	4·25
7 atoms water .	7·875
	17·125

There is no reason to doubt that this oxide is a compound of 1 atom nickel and 1 atom oxygen. An atom of nickel, therefore, must weigh 3·25.

Atom of nickel.

3. Besides the protoxide of nickel there is another oxide, having a black colour, which was first pointed out by Thenard, and which he obtained by passing a current of chlorine gas through water, having protoxide of nickel suspended in it. A portion of the oxide dissolves in the muriatic acid evolved, while another portion assumes a black colour and is converted into peroxide. It will be obvious, from the account given below of the constitution of this oxide, that $\frac{1}{3}$d of the protoxide of nickel must be dissolved and converted into muriate of nickel, while $\frac{2}{3}$ds become peroxide of nickel and remain undissolved.

Atom of peroxide of nickel.

When peroxide of nickel is dissolved in ammonia, an effervescence takes place, owing to the escape of azotic gas: for the peroxide is converted into protoxide at the expense of the hydrogen of the ammonia. An effervescence also

takes place when this oxide is digested in acids: the excess of oxygen flies off in the state of gas, and the protoxide thus formed unites with the acid. From some experiments of Rothoff, quoted by Berzelius,* it would appear that the oxygen in peroxide of nickel is to that in the protoxide as 3 to 2. If this be the case, the atomic weight of peroxide of nickel will be 4·75, and it will be a compound of

1 atom nickel . .	3·25
1½ atom oxygen . .	1·5
	4·75

If this supposition be well founded, 47·5 grains of peroxide of nickel, when dissolved in sulphuric acid, will lose 5 grains, or 14·754 cubic inches of oxygen gas.

SECT. III.

OF THE ATOMIC WEIGHT OF COBALT.

The sulphate of cobalt, when pure, crystallizes in small red rhombic prisms, very similar to the crystalline form of protosulphate of iron. It may be exposed to an incipient red heat, and

* Annals of Philosophy, III. 355.

deprived of the whole of its water of crystallization without losing any of its acid.

Sulphate of cobalt analyzed.

1. 9·25 grains of anhydrous sulphate of cobalt were dissolved in water, and the liquid mixed with a solution of 13·25 grains of chloride of barium. A double decomposition took place; sulphate of barytes precipitated, and the clear residual liquid being examined, was not affected by sulphate of soda or muriate of barytes—showing that it contained neither barytes nor sulphuric acid. From this experiment it is obvious, that 9·25 grains of anhydrous sulphate of cobalt contain exactly 5 grains of sulphuric acid: the remaining 4·25 grains must be protoxide of cobalt. Consequently, this salt is composed of

Sulphuric acid . .	5
Protoxide of cobalt .	4·25
	9·25

Atom of protoxide of cobalt.

The salt being neutral, and 5 being the atomic weight of sulphuric acid, 4·25 must be the atomic weight of protoxide of cobalt.

2. When 17·125 grains of crystallized sulphate of cobalt are exposed to an incipient red heat in a platinum crucible, they lose 7·875 grains of their weight. Now, this is equivalent to 7 atoms of water. It is obvious from this experiment, that sulphate of cobalt is composed precisely as sulphate of nickel, or of

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1 atom sulphuric acid	5
1 atom protoxide of cobalt	4·25
7 atoms water . .	7·875
	17·125

3. There seems no reason to hesitate about considering this oxide as a compound of 1 atom oxygen and 1 atom cobalt. On that supposition, the atomic weight of cobalt will be 3·25, the same as the atomic weight of nickel. Atom of cobalt.

4. If protoxide of cobalt be a compound of 1 atom cobalt and 1 atom oxygen, it follows, that 100 parts of this oxide are composed of

Cobalt . . .	76·47
Oxygen . . .	23·53
	100·00

Now, when the protoxide of cobalt is precipitated from an acid, edulcorated and dried in the open air, it absorbs oxygen during the drying, and is converted into a black powder, which is the *peroxide* of cobalt. This peroxide dissolves with effervescence in muriatic acid, while chlorine gas is disengaged. When heated, it gives out oxygen gas; and, from the experiments of Rothoff, as stated by Berzelius,* it appears, that when 111 grains of peroxide of cobalt are heated, they are converted into 100 grains of protoxide: so that

* Annals of Philosophy, III. 356.

100 grains of protoxide become peroxide by uniting with 11 grains of oxygen. But $11 \times 2 = 22$, which approaches very near the oxygen in 100 grains of protoxide.

Atom of peroxide of cobalt.

From this we see that the oxygen in the protoxide is to that in the peroxide as 2 to 3. Consequently, the atomic weight of peroxide of cobalt must be 4·75, and it must be a compound of

1 atom cobalt	3·25
1½ atom oxygen	1·5
	4·75

Thus its composition and weight agree with those of peroxide of nickel; like that peroxide, it does not appear capable of uniting with acids, nor of entering into any permanent combinations like the peroxide of iron.

SECT. IV.

OF THE ATOMIC WEIGHT OF MANGANESE.

The atomic weight of the protoxide of this metal may be made out from the protosulphate in the same way as the protoxide of iron, nickel, and cobalt. Protosulphate of manganese, when pure, forms large transparent crystals, having a beautiful flesh colour, and the shape of a very oblique rhombic prism, the faces of which meet

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at angles of about 148° and 32°. Its taste is somewhat similar to that of Glauber's salt, but rather more disagreeable; and like that salt, it acts as a cathartic when taken to the extent of about half an ounce. It is very soluble in water, but is not altered by exposure to the air, whether the atmosphere be dry or moist.

Sulphate of manganese analyzed.

1. 15·125 grains of these crystals were dissolved in water, and the liquid mixed with a solution of 13·25 grains of chloride of barium. A double decomposition took place, and when the sulphate of barytes had subsided, the residual liquid was neither affected by sulphate of soda nor muriate of barytes. From this experiment it follows, that 15·125 grains of protosulphate of manganese contain exactly 5 grains of sulphuric acid.

2. When 15·125 grains of protosulphate of manganese are heated in a platinum crucible, they melt, and the water of crystallization is gradually dissipated. But it is scarce possible, by this process, to drive off the whole water of crystallization without allowing some of the acid at the same time to escape. Dr. John, from 15·125 grains of this salt, drove off 5·345 grains of water. I repeated this experiment with great care, and found that I could disengage 5·48 grains of water from 15·125 grains of the salt. But if the heat was raised high enough to produce a greater diminution of weight, a portion of the salt was

altered in its appearance, and rendered insoluble.

Five atoms of water weigh 5·625, which weight exceeds 5·48 by only 0·145, or about the eighth part of an atom. There is no reason to doubt that the aqueous portion of this salt constitutes a determinate number of atoms; and since 15·125 of the salt contain exactly one atom of sulphuric acid, the atomic weight of the water must exist also in the same quantity. Now, the results just stated point out unequivocally that five atoms of water are united in it with an integrant particle of anhydrous protosulphate. Thus it appears, that 15·125 grains of protosulphate of manganese contain 5·625 grains of water.

3. The five grains of sulphuric acid and the 5·625 grains of water make together 10·625 grains. This quantity, subtracted from the original weight, leaves 4·5, which must denote the quantity of protoxide of manganese present. Thus it appears, that protosulphate of manganese is composed of

Sulphuric acid	5
Protoxide of manganese	4·5
Water . . .	5·625
	15·125

Atom of protoxide of manganese.

As the salt is neutral, and as 5 is the weight of an atom of sulphuric acid, 4·5 must be the atomic weight of protoxide of manganese.

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Thus it appears, that protoxide of manganese and protoxide of iron have the same atomic weight. If protoxide of manganese be a compound of one atom manganese and one atom oxygen, (as there is the strongest reason for believing) then an atom of manganese weighs 3·5, or the same as an atom of iron.

Native black oxide.

4. Manganese occurs most commonly in the state of a black coloured oxide, which has been long employed to deprive glass of its colour, and is at present consumed in great quantities by the bleachers and the preparers of the bleaching powder. This black oxide is most commonly impure; but it occurs occasionally crystallized in small needles, which have the form of rhombic prisms, and the lustre and colour of iron, though rather darker. I have met with specimens of this kind perfectly pure. When 11 grains of this pure oxide are kept for some time in a low red heat in a platinum crucible, they lose exactly one grain of their weight, which consists of pure oxygen gas. By this exposure to heat, the metallic lustre disappears, and the mass assumes a brownish black colour. The powder thus formed is a peculiar oxide of manganese; for it dissolves without effervescence in sulphuric and in muriatic acid, and forms dark red coloured solutions. This sulphate and muriate do not crystallize;—indeed, when the muriate is heated, chlorine gas is evolved, and

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the common colourless protomuriate of manganese obtained. But the red sulphate of manganese may be concentrated without losing its colour. Sulphurous acid, or nitrous acid, instantly renders it colourless, by depriving it of the excess of oxygen which it contains above the protosulphate.

Deutoxide of manganese.

Thus, besides the protoxide of manganese, there are two other oxides, both of which are *black*. I determined the composition of the brownish black oxide in the following way: A quantity of carbonate of manganese, which I knew to contain exactly 45 grains of protoxide, was dissolved in nitric acid in a platinum crucible; the solution was evaporated to dryness, and the crucible with its contents was then exposed to a red heat: by this means, the nitric acid was decomposed, and driven off, and a black shining powder obtained, which weighed exactly 50 grains. This black powder possesses the same properties with the brownish black powder obtained by exposing native black oxide of manganese to a low red heat—for it forms the same red coloured solutions with sulphuric and muriatic acids, which are rendered colourless by sulphurous acid, or when heated with sugar.*

* When carbonate of manganese is exposed to a red heat, it assumes a brown colour; but is not converted into deutoxide, unless it be previously mixed with nitric acid. A quantity of carbonate containing 4·5 grains of protoxide of manganese, when thus treated, instead of weighing 5 grains as it would do if it were converted into deutoxide, only weighs 4·8 or

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Thus it appears, that 45 protoxide of manganese become 50 deutoxide; or, 4·5 protoxide become 5 deutoxide: but 4·5 is the atomic weight of protoxide of manganese, and it contains 1 atom of oxygen. Five, therefore, must be the atomic weight of deutoxide; and it is obviously a compound of

1 atom manganese	3·5
1½ atom oxygen	1·5
	5·0

It is, therefore, similar in its composition to the peroxide of iron. As its colour is either a brownish black, or a shining black, according to the mode of preparing it, we cannot with propriety distinguish it by its colour; and shall, therefore, henceforth give it the name of *deutoxide of manganese.*

5. The composition of deutoxide of manga-

perhaps 4·83; showing that it is still partly in the state of protoxide. This is the *oxydum manganoso-manganicum* of Arfwedson, which he considers as composed of

1 atom protoxide	4·5
2 atoms deutoxide	10
3)14·5	
4·8333 = atomic weight of the compound.	

When the black oxide is exposed to too high a temperature, it becomes analogous to this in its composition, showing that it is partly converted into protoxide.

nese being known, it is easy, from what has been already said, to determine the composition of the native black oxide employed by manufacturers: 11 black oxide, when heated to redness, lose 1 of oxygen, and become 10 deutoxide; or, which is the same thing, 5·5 black oxide, when deprived of 0·5 oxygen, become 5 deutoxide; consequently, the atomic weight of native black oxide is 5·5, and it is obviously composed of

Atomic weight of tritoxide.

1 atom manganese	3·5
2 atoms oxygen	2
	5·5

This is an oxide not analogous to any of the known oxides of iron, nickel, or cobalt. It has been hitherto distinguished by the name of *peroxide of manganese;* but, as there is reason to believe that manganese forms at least one, if not two additional oxides, it will be better henceforth to call it *tritoxide of manganese.*

Chameleon mineral.

6. Scheele, many years ago, made a curious experiment with the tritoxide of manganese. He mixed it with caustic potash, and exposed it to a heat sufficiently strong to melt the alkali. The fusion being kept up for some time, a dark green, or blackish mass was formed, which was soluble in water. By degrees, a yellow powder precipitates from this solution, and the liquid assumes a *blue* colour; some time after, the co-

lour becomes *violet*, and then *red*; and, finally, black oxide of manganese precipitates, and the liquid loses all colour. In consequence of this curious succession of colours, the liquid thus obtained used to be distinguished by the name of mineral chameleon. We may employ saltpetre instead of potash, and the process will succeed equally well. When the liquid had assumed a red colour, Chevillot and Edwards* concentrated it by evaporation, and obtained a red coloured salt in needles. This salt is neutral, and is composed of potash, united to an oxide of manganese, which possesses acid properties, and which, consequently, is different from the three oxides, which have been already noticed.

Manganate of potash.

This red salt has received the name of *manganate of potash*. It possesses some singular properties. It crystallizes in four-sided rectangular prisms, has the diamond lustre, a purple colour, and a taste at first sweet, and similar to that of walnuts, but which leaves a very disagreeable impression in the mouth. When these crystals are heated, in contact with hydrogen gas, they set it on fire. They detonate violently with phosphorus, set fire to sulphur, antimony, and arsenic, and rival chlorate of potash itself in their power of supporting combustion. The acid cannot be separated from this salt without de-

* Ann. de Chim. et de Phys. VIII. 337.

composition. Sulphuric acid disengages it from the potash; but when we endeavour to separate the sulphate of potash by evaporation, the red colour disappears, and tritoxide of manganese precipitates.

Forchhammer's mode of obtaining manganesic acid.

But Dr. Forchhammer succeeded by a very ingenious process in obtaining *manganesic acid* in a separate state, or at least combined merely with water. He mixed together tritoxide of manganese and crystallized nitrate of barytes, and exposed the mixture to a heat just sufficient to produce the fusion of the salt. Great care, he says, must be taken not to drive off the water of crystallization, otherwise the process does not succeed.* The nitric acid is gradually decomposed. The tritoxide of manganese unites with more oxygen, is converted into an acid, and combines with the barytes, as that alkali is disengaged. After the process is finished, the mass must be digested in water, which dissolves any pure barytes, or nitrate of barytes, that may be present; but does not touch the compound of barytes and acid of manganese, which is insoluble in that liquid. To this insoluble residuum Dr. Forchhammer added the quantity of sulphuric acid just capable of saturating all the barytes which it contained. The acid of manganese in the

* I have not attempted to repeat this process, because I have never met with any nitrate of barytes that contained any water of crystallization. As far as my observations go, the salt is always anhydrous.

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mass is immediately resolved into two substances, tritoxide of manganese, and manganesic acid. The former remains mixed with the sulphate of barytes; but the latter dissolves in water, and gives that liquid a beautiful red colour.

7. When tritoxide of manganese and nitre are heated, the solution is at first green, and it gradually passes into red, while, at the same time, a quantity of deutoxide of manganese precipitates. When an acid is poured into the green coloured solution, it becomes red; an alkali, on the other hand, renders the red coloured solution green. When alcohol, or any animal or vegetable substance, is added to the red solution, deutoxide of manganese precipitates; while, at the same time, the red colour is destroyed.

Dr. Forchhammer is of opinion, from these and similar phenomena, that there are two acids of manganese, which he calls *manganous* and *manganesic* acids—the former containing the least, and the latter the most oxygen. The manganous acid exists in the green coloured liquid, which is a compound of that acid and potash; while the red salt is a compound of manganesic acid and potash.

His method of analyzing manganous acid,

8. To determine the composition of manganous acid, Dr. Forchhammer prepared a quantity of the manganite of potash, and decomposed it by the addition of a solution of nitrate of lead. A dark coloured precipitate fell, consisting of a

combination of peroxide of lead and deutoxide of manganese; and this precipitate he considered as containing all the oxygen and all the manganese which existed in the manganous acid. This precipitate, being washed and dried, was mixed with bisulphate of potash, and exposed to a heat capable of fusing it in a retort. The oxygen gas given out was collected and measured; its weight was 0·1303 parts. The salt in the retort was dissolved in water (the lead remaining behind in the state of sulphate); the manganese was precipitated by carbonate of soda, and exposed to a red heat. The deutoxide obtained by this process weighed 0·282 parts.

Now, deutoxide of manganese is (as we have seen) a compound of 3·5 manganese + 1·5 oxygen; consequently, 0·282 parts of this oxide contain

Manganese	.	0·1974
Oxygen	.	0·0846
		0·2820

If to this portion of oxygen we add the 0·1303 parts driven off by heat, we shall have manganous acid composed of

Manganese	0·1974	or	3·5
Oxygen	0·2149	-	3·8103
	0·4123		

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Now, 3·8103 approaches nearly to 4 atoms of oxygen—from which it would appear, that manganous acid is a compound of 1 atom manganese and 4 atoms oxygen; and that its atomic weight is 7·5. But Dr. Forchhammer concludes (though I do not see the force of his reasoning), that, in reality, manganous acid contains only 3 atoms of oxygen, united to 1 atom of manganese. Its atomic weight, on that supposition, will be 6·5.

And manganesic acid.

Dr. Forchhammer's process of experimenting and reasoning, by which he made out the composition of manganesic acid, is very ingenious, but rather abstruse. I shall endeavour to lay a simple view of it before the reader:—Through a solution of manganite of potash, he passed a current of carbonic acid gas. By this process the manganite was converted into manganate of potash; while, at the same time, 0·136 parts of deutoxide of manganese were thrown down. The manganate was then decomposed, by means of alcohol; 0·214 parts of deutoxide of manganese were precipitated. Now, by the first process, the manganesic acid formed contained all the oxygen in the manganous acid, except what remained in the portion of the deutoxide separated. The whole deutoxide separated was 0·136 + 0·214 = 0·350; and this was the quantity of deutoxide contained in the manganous acid. The manganesic acid contained only 0·214 parts; and with these 0·214 parts

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there was combined just as much oxygen as with the 0·350 parts in the manganous acid.

But manganous acid is composed of 5 deutoxide of manganese + 1·5 oxygen; consequently, 0·350 are composed of 0·245 deutoxide + 0·105 oxygen; and manganesic acid is a compound of

Deutoxide of manganese	0·214
Oxygen . .	0·105

Deutoxide of manganese is a compound of 3·5 manganese + 1·5 oxygen; consequently, 0·214 deutoxide consists of 0·1498 manganese + 0·0642 oxygen. By adding together the 0·105 oxygen and the 0·0642, we obtain 0·1692 for the whole oxygen in manganesic acid, combined with 0·1498 of manganese. Thus it appears, that manganesic acid is a compound of

Manganese	0·1498	or	3·5
Oxygen	0·1692	-	4·620
	0·3190		

If we make the same allowance for excess of oxygen that Dr. Forchhammer made in the case of manganous acid, manganesic acid may be considered as a compound of 1 atom manganese and 4 atoms oxygen, which would make its atomic weight 7·5.

It would appear from the preceding investigation, that oxygen and manganese combine in no

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fewer than 5 proportions, and form 5 oxides, the composition of which is as follows:

Oxides of manganese.

	MANGANESE.	OXYGEN.
1 Protoxide . . .	3·5	+ 1
2 Deutoxide . . .	3·5	+ 1·5
3 Tritoxide . . .	3·5	+ 2
4 Manganous acid . .	3·5	+ 3
5 Manganesic acid . .	3·5	+ 4

9. Berzelius describes an oxide of manganese containing less oxygen than any of the preceding. It was obtained by leaving metallic manganese for more than a year in a phial not very closely corked. It fell into a dark coloured powder, which, according to Berzelius' analysis, or rather calculation, was a compound of

Manganese . .	100
Oxygen . .	10·666

I have had no opportunity of making any experiments on this supposed oxide: but, if it exist, it must be a compound of 3 atoms manganese with 1 atom oxygen. This would consist of

Manganese	10·5	or	100
Oxygen	1·0	-	9·5238

which differs but little from the estimate of Berzelius.

Suboxide of manganese.

10. Dr. John found, that when metallic manganese is put into water, that liquid was slowly

decomposed ;—hydrogen gas being evolved, while the manganese lost its metallic lustre and assumed a green colour : 80 parts of manganese thus treated, became 92 parts of the new oxide. Now, 80 : 12 : : 3·5 : 0·525. Hence it would appear that this oxide, which I have not had an opportunity of examining, is a compound of 1 atom manganese and half an atom of oxygen ; or of

2 atoms manganese . .	7
1 atom oxygen . . .	1
	8

This oxide is incapable of uniting with acids ; but Dr. Forchhammer has made a set of experiments to show that it combines with sulphur, and that it constitutes the mineral found in Transylvania and Cornwall, and considered at present as a sulphuretted oxide of manganese. It seems, however, proved that the Transylvanian ore is a sulphuret of manganese.

I think the existence of the supposed protoxide of manganese of Berzelius exceedingly doubtful. But I see no reason to doubt the existence of the suboxide of John—though that chemist was mistaken in considering it as the basis of the salts of manganese. The real basis is the substance which I have here distinguished by the name of protoxide, and which contains just twice as much oxygen as the suboxide of John.

Of all the substances hitherto examined, manganese is capable of uniting with the greatest number of doses of oxygen.

SECT. V.

OF THE ATOMIC WEIGHT OF CERIUM.

CERIUM has not hitherto been obtained in the metallic state; but it has been ascertained that it combines with two proportions of oxygen, and forms two oxides; both of which possess alkaline properties, and are capable, of consequence, of combining with acids, and of constituting the bases of a variety of salts.

Muriate of cerium analyzed by Hisinger.

The only person who has hitherto attempted to determine the atomic weight of this metal and its oxides, is M. Hisinger. His deductions were made from an analysis of the protomuriate of cerium. A quantity of this salt was dissolved in water, and the muriatic acid thrown down by nitrate of silver. The chloride of silver, after fusion, weighed 1·819, equivalent to 0·4609 parts of muriatic acid. The solution having been freed by muriatic acid from the excess of silver which it contained, was mixed with carbonate of ammonia to throw down the protoxide of cerium. This oxide, after being heated to redness in a close vessel, weighed 0·684 parts.* From this

* Annals of Philosophy, IV. 355.

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analysis it follows, that protomuriate of cerium is composed of

Muriatic acid	0·4609	or	4·625
Protoxide of cerium	0·684	-	6·862

As the salt was neutral, the conclusion to be drawn from this analysis is, that the atomic weight of protoxide of cerium is 6·862.

But I think there is reason to suspect that the muriatic acid in this analysis is somewhat overrated, and the protoxide of cerium somewhat underrated:—at least, I generally find, that when nitrate of silver is poured into the solution of a metalline salt, the chloride obtained contains traces of the metal previously in combination with the muriatic acid. In order to obtain correct results from the analysis of a metalline muriate, the metallic oxide should be thrown down in the first place, by means of an alkaline carbonate or pure alkali; and after the metallic oxide has been separated by the filter, the liquid is to be neutralized by nitric acid, and the muriatic acid thrown down by nitrate of silver.—These considerations induced me to make the following experiments in order to determine the atomic weight of protoxide of cerium.

Experiments of the author.

1. A quantity of oxalate of cerium was exposed to a red heat, in order to destroy the acid which it contained. The peroxide of cerium thus obtained, was dissolved in muriatic acid, and the liquid was repeatedly evaporated to dry-

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ness with an excess of acid till it became quite colourless. Carbonate of ammonia was then mixed with it in sufficient quantity to throw down the protoxide of cerium in the state of a carbonate. The carbonate of cerium, when allowed to dry in the open air, was a very light, bulky, white, tasteless substance, in small scales or plates, somewhat resembling the appearance of earthy talc. It was dissolved in dilute sulphuric acid till the acid refused to take up any more. The solution was colourless, and on being sufficiently concentrated deposited protosulphate of cerium in small crystals, which had the form of six-sided prisms, and some of them seemed to be three-sided prisms; but they were too small to admit of any thing like an accurate measurement of their angles.

This salt has a flesh colour, a sweet taste, with a slight degree of astringency, and the property of reddening vegetable blues. It is pretty soluble in water; though the precise degree was not determined.

Protosulphate of cerium analyzed.

2. 15·625 grains of these crystals were dissolved in distilled water, and the liquid mixed with a similar solution of 13·25 grains of chloride of barium. A double decomposition took place, sulphate of barytes precipitated, and the residual liquid was not affected by sulphate of soda nor muriate of barytes. Hence, it contained no sensible quantity of sulphuric acid, or

barytes. From this experiment it follows, that 15·625 grains of protosulphate of cerium contain 5 grains of sulphuric acid.

3. 15·625 grains of the crystals of protosulphate of cerium were exposed for an hour on the sand bath to a heat of about 500° or rather more. The loss of weight was 3·125 grains; and this loss was not increased though the heat was continued for twenty four hours. The salt thus treated, had become white. It still reddened vegetable blues, and was completely soluble in water. Hence, the loss of weight must be ascribed to the escape of water. Now, the weight of three atoms of water is equivalent to 3·375 grains. This exceeds the loss of weight, actually sustained by the salt, by 0·25 grains, equivalent to $\frac{1}{13}$th of an atom. The salt being as neutral as possible, and 15·625 grains of it containing 5 grains of sulphuric acid, which is equivalent to an atom, the same weight of salt must contain a determinate number of atoms of water; and it is obvious, that the true quantity of water must be 3 atoms, or 3·375 grains. I found that the salt could not be rendered perfectly anhydrous without at the same time losing a portion of its acid.

4. Five sulphuric acid, and 3·375 water added together make 8·375, which being subtracted from 15·625, the total quantity of salt used, leaves 7·25, which must represent the weight of

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protoxide of cerium in the salt, and must also be the atomic weight of that protoxide.

From the preceding analysis the reader will perceive, that protosulphate of cerium is composed of

1 atom sulphuric acid .	5
1 atom protoxide of cerium	7·25
3 atoms water . .	3·375
	15·625

7·25, then, is the true atomic weight of protoxide of cerium, which is a little higher than the number deduced from Hisinger's analysis of the muriate of cerium. The probable reason for this difference has been already hinted at. Atom of protoxide of cerium.

5. According to Hisinger's experiments the oxygen in the protoxide of cerium is to that in the peroxide as 2 to 3. My stock of cerium was not sufficient to enable me to make a similar set of experiments on peroxide of cerium. But there is every reason to confide in the ratios which Hisinger has deduced from his analyses; all of which, having been made in the same way, would be subject to the same errors, which would not affect the ratios between the two oxides, though it had an effect upon their absolute weights. It is easy from these ratios to deduce the atomic weights and composition of cerium and its oxides, as follows: Of peroxide of cerium.

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	ATOMIC WEIGHT.		CERIUM.		OXYGEN.	
Cerium	6·25					
Protoxide	7·25	composed of	1	atom +	1	atom
Peroxide	7·75		1	+	1½	

Action of reagents.

6. The following experiments to determine the effects of reagents on protomuriate of cerium, though they contain little novelty, are perhaps worth recording; because the salts and all the reagents used were exceedingly pure.

1. Prussiate of potash—A chalky white precipitate.
2. Gallic acid and infusion of galls—○.
3. Oxalic acid—A copious white precipitate.
4. Oxalate of Ammonia—Ditto, redissolved by agitation.
5. Tartaric acid—○.
6. Tartrate of potash—A copious white precipitate.
7. Bitartrate of potash—○.
8. Phosphoric acid—A white precipitate.
9. Phosphate of soda—Abundance of white flocks.
10. Carbonate of ammonia—A milk white flocky precipitate.

CHAP. XI.

OF THE ATOMIC WEIGHTS OF ZINC, CADMIUM, LEAD, TIN, BISMUTH, COPPER, MERCURY, AND SILVER.

THESE eight metals possess several properties in common by which they are distinguished from all the other metals. 1. They all possess a certain degree of malleability; for bismuth, by far the most brittle of them all, may be dimpled by a blow of the hammer; and zinc, the next in order, is very malleable at a temperature somewhat above that of boiling water. 2. They all melt at rather low temperatures, when compared with the melting point of most of the other metals; for copper, which requires the greatest heat to melt it, may be fused in a common fire urged by bellows. It requires some care to keep a silver crucible red hot in a common fire without fusing it. The other six melt in a heat below redness. Indeed, mercury requires so very little heat to melt it, that it remains always fluid even in our coldest winter weather. 3. Their oxides are easily decomposed by heat and charcoal, so that there is no difficulty in obtaining

Characters of the metals treated of in this chapter.

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these bodies in the metallic state, and, comparatively speaking, in a state of considerable purity. 4. When the last seven of these metals are held in solution by an acid (particularly sulphuric, or muriatic, when these acids form soluble salts with the metallic oxide) if we introduce into the solution a plate of zinc, the metal previously in solution is thrown down in the metallic state, while a corresponding portion of the zinc is dissolved in its place. A plate of cadmium introduced into a solution of any of the six metals placed after it in the title of this chapter, will also throw it down in the metallic state, while a corresponding portion of the cadmium enters into solution. In like manner a plate of lead will throw down any of the five metals after it in the metallic state. A plate of tin will throw down any of the four metals after it; a plate of bismuth, any of the three metals after it; a plate of copper either of the two metals after it; and mercury will throw down silver in the metallic state.

But silver is incapable of throwing down any of the other metals mentioned in the title of this chapter, though it is itself thrown down by them all. Mercury throws down silver, but none of the others; copper throws down mercury and silver, but none of those that precede it. The same remark applies to every particular metal; it throws down all those which are placed

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after it in the title of the chapter, but none of those that are placed before it.

Iron has likewise the property of throwing down all the metals belonging to this chapter, except zinc, in the metallic state. When a plate of zinc is put into a solution of iron, the iron falls very slowly in the state of peroxide. Copper is a good precipitant of mercury and silver; zinc precipitates cadmium, tin, and copper very well from muriatic acid, and lead very well from acetic acid.

The reader will recollect that the atomic weight of zinc was established in the first section of the first chapter of this work. The knowledge of it was necessary in order to enable us to determine the specific gravities of oxygen and hydrogen gases, upon which the whole doctrine of atomic proportions ultimately depend. The weight of an atom of zinc is 4·25; it combines with only one proportion of oxygen, and forms one oxide, the atomic weight of which is 5·25. Atom of zinc.

SECT. I.

OF THE ATOMIC WEIGHT OF CADMIUM.

Cadmium is still a very scarce metal; but by the kindness of Mr. Harepath, I was favoured

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with a quantity of the matter which adheres to the roof of the room in which zinc is smelted in Bristol. This sublimate contains about ten per cent. of cerium; by extracting it, I have had it in my power to examine the constitution of its different salts. Stromeyer, to whom we are indebted for our knowledge of this metal, has analyzed several of its salts, and ascertained how much the metal increases in weight when it is converted into an oxide: and from the well known precision of this excellent chemist, we have every reason to expect that the results of his analyses will give us the atomic weight of this metal, at least exceedingly near the truth. It will be proper, therefore, in the first place to state his experiments.

M. Stromeyer analyzed the carbonate, sulphate, nitrate, muriate, phospate, and borate of cadmium. He has not yet published the details of his analyses; or at least, the second volume of his *Untersuchungen*, in which they will probably be found, has not yet reached Great Britain. This puts it out of our power to judge of the accuracy of the data which he employed in his calculations. Under this uncertainty, I shall make choice of the sulphate to determine the atomic weight of cadmium, because I know from other analyses which he has published in detail, that he employs the constituents of sulphate of barytes as given by Berzelius, which,

though not rigidly exact, approach exceedingly near the truth.

Analysis of sulphate of cadmium by Stromeyer.

According to Stromeyer, sulphate of cadmium has a good deal of resemblance to sulphate of zinc in its appearance. Its crystals are four-sided rectangular prisms, which are very soluble in water, and effloresce rapidly when exposed to the air. Heat easily drives off the water of crystallization; but the salt may be exposed to a red heat without losing any of its acid; this makes it easy to determine its water of crystallization. The constituents of this salt as determined by Stromeyer are

Sulphuric acid .	28·5230
Oxide of cadmium	45·9564
Water . . .	25·5206
	100 *

Now, these numbers bear to each other the same ratios as the following:

Sulphuric acid .	5
Oxide of cadmium	8·0567
Water . .	4·454

It will be obvious to the reader that 5 is the number which denotes the atomic weight of sulphuric acid; 4·454 is so near 4·5, which represents the weight of four atoms of water, that we

* Gilbert's Annalen, LX. 202.

can have no doubt that four atoms is the exact quantity of water in an integrant particle of the salt. It is more than probable that the 0·046, which is wanting to complete the weight of the four atoms of water, has been given to the oxide of cadmium. Hence, it is likely that the constituents of the salt should have been stated as follows:

1 atom sulphuric acid	=	5
1 atom oxide of cadmium	=	8·0107
4 atoms water	=	4·5

8·0107 denote the weight of an atom of oxide of cadmium, according to this analysis—a number approaching 8 so nearly, that we can have no hesitation in making choice of 8 as the true atomic weight of this oxide. For it is obvious from the great number of atoms already investigated, as well as to be investigated, that all the atomic weights of simple bodies are multiples of 0·25. Now, 8 is such a multiple; while neither 8·0567 nor 8·0107 is so.

To determine the composition of sulphate of cadmium with the requisite exactness, I prepared a quantity of very pure crystals, by crystallizing a rather concentrated solution of the salt under the exhausted receiver of the air-pump over sulphuric acid. The crystals were large, flat, four-sided prisms, apparently rectangular, but from their efflorescing property, I was not able to measure their angles by the reflecting goniometer. In most of them, the edges were

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truncated, rendering the prism hexagonal, and it was terminated at both extremities by an elongated hexagon. These crystals, after four successive crystallizations, still reddened vegetable blues. Hence, I conclude that oxide of cadmium, like oxide of zinc, is incapable of completely neutralizing sulphuric acid. The taste of the salt has some resemblance to that of sulphate of zinc; but it is rather more acrid and disagreeable.

Guided by the analysis of Stromeyer given above, I dissolved 17·5 grains of these crystals, dry, but quite free from efflorescence, in water, and mixed the solution with one of 13·25 grains of chloride of barium. After the sulphate of barytes had subsided, the supernatant liquid was tested by sulphate of soda and muriate of barytes, but it was not affected by either. From this we see that 17·5 grains of crystallized sulphate of cadmium contain just 5 grains of sulphuric acid. Experiments of the author.

17·5 grains of the same crystals, heated very cautiously to redness in a platinum crucible, lost just 4·5 grains, which is equivalent to 4 atoms of water.

The acid and water in 17·5 grains of sulphate of cadmium amounting to 9·5 grains, it is obvious, that the 8 grains wanting to make up the whole weight must be oxide of cadmium; and that the true composition of the salt is

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1 atom sulphuric acid	5
1 atom oxide of cadmium	8
4 atoms water .	4·5
	17·5

I placed an exceedingly concentrated solution of sulphate of cadmium, along with sulphuric acid, under the exhausted receiver of an air pump. Instead of crystallizing, the liquid deposited a white, hard, shapeless crust, similar in appearance to enamel. When a solution of 15·25 grains of this crust was mixed with a solution of 13·25 grains of chloride of barium, a double decomposition took place; and after the sulphate of barytes had subsided, the supernatant liquid was tested with sulphate of soda and muriate of barytes, but was not affected by either. Hence the constituents of this crust are

1 atom sulphuric acid	5
1 atom oxide of cadmium	8
2 atoms water .	2·25
	15·25

Sulphate of zinc has the property of being deposited in the same way, as was shown in the first section of the third chapter of this work.

Several of the other salts of cadmium were likewise analyzed. The results, which will be seen in a subsequent chapter, all coincide to

show that 8 is the atomic weight of oxide of cadmium. Atom of oxide of cadmium.

As cadmium unites with only one dose of oxygen, it is obvious that the oxide is a compound of one atom cadmium and one atom oxygen; consequently, the atomic weight of cadmium must be 7. This is corroborated by Stromeyer's experiments. He found that 100 cadmium, when oxydized, were converted into 114·352 of oxide of cadmium. Therefore, oxide of cadmium is composed of Atom of cadmium.

Cadmium	100	or	6·9677
Oxygen	14·352	-	1

6·9677, the atomic weight of cadmium, deduced from this experiment, approaches very nearly to 7, the number deduced from the sulphate. That it should be rather less than 7 is not surprizing; for cadmium is so volatile a metal, that it is not easy to expose it to heat, without some loss.

Stromeyer likewise formed and analyzed some alloys of cadmium. They deserve our attention, because they serve to corroborate the accuracy of the atomic weight which has been assigned to cadmium.

The alloy of cadmium and platinum is a compound of Alloy of cadmium and platinum.

Platinum	46·02	or	12
Cadmium	53·98	-	14·07
	100·00*		

* Gilbert, LX. 209.

It will appear hereafter, that the 12 represents the atomic weight of platinum. 14·07 must denote two atoms of cadmium; for the alloy consists obviously of 1 atom of platinum, united to 2 atoms of cadmium. The atom of cadmium, deduced from this alloy, is 7·035.

Amalgam of cadmium.

The amalgam of cadmium is composed of

Cadmium	21·7391	or 6·944
Mercury	78·2609	- 25
	100	

25 is the atomic weight of mercury, so that the amalgam is a compound of 1 atom mercury, and 1 atom cadmium. The atomic weight of cadmium, deduced from this amalgam, is 6·944.

The atom of cadmium, deduced from a mean of these two alloys, is 6·9895; and if we deduce the atomic weight of this metal from a mean of these four sets of experiments of Stromeyer, which is the most likely way to come at the truth, we obtain 7·00085. Now, this approaches so very near 7, that the most scrupulous chemist cannot hesitate about adopting 7 as the true atomic weight of this metal; so that the experiments of Stromeyer, even without mine, are sufficient to establish that important point.

Thus it appears that an atom of cadmium weighs 7, and an atom of oxide of cadmium 8. Sulphuret of cadmium, when digested in nitric

acid, is converted into sulphate of cadmium. It is, therefore, a compound of one atom sulphur and one atom cadmium, and its atomic weight is 9.

SECT. II.

OF THE ATOMIC WEIGHT OF LEAD.

I HAVE already in a former section of this work described an experiment, from which the atomic weight of protoxide of lead is easily deduced. Nitrate of lead crystallizes in white opaque octahedrons, and is quite anhydrous. 20·75 grains of it are just decomposed by 11 grains of anhydrous sulphate of potash; and the sulphate of lead obtained weighs exactly 19 grains. Now, these 19 grains contain 5 grains of sulphuric acid; so that the salt must be a compound of

Sulphuric acid .	5
Protoxide of lead	14
	19

The salt being neutral, and 5 representing the weight of an atom of sulphuric acid, 14 must represent the weight of an atom of protoxide of lead. Atom of protoxide of lead.

If it be a compound of 1 atom lead and 1 atom oxygen, then an atom of lead weighs 13; and that 13 is the true weight of an atom of lead Atom of lead.

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will appear from the following experiment: 15 grains of pure galena or sulphuret of lead were reduced to powder, and digested with nitric acid in a small retort, the weight of which had been previously ascertained, and marked upon it with a diamond. By this process the galena was gradually converted into sulphate of lead. When the conversion was completed, the nitric acid was distilled off, and the retort was kept in a heat of above 600°, till it became quite dry in the inside; it was then allowed to cool, and the weight of the sulphate of lead thus formed was exactly 19 grains. Now, 5 of these grains are sulphuric acid, containing 2 grains of sulphur; consequently, 2 represents the quantity of sulphur in 15 grains of sulphuret of lead. The remainder of the weight being lead, it is obvious that sulphuret of lead is composed of

Lead . .	13
Sulphur . .	2
	15

2 represents the weight of an atom of sulphur, and 13 is obviously the atomic weight of lead.

2. Besides the protoxide, or yellow oxide of lead, there are two other oxides of this metal; namely, the *red oxide*, or *deutoxide*, and the *brown oxide*, or *peroxide*.

Composition of red lead.

The beautiful pigment called *red lead*, is a

mixture of deutoxide and protoxide in variable proportions. In some very beautiful red lead, I have found the proportion of protoxide amount to nearly one-half of the whole weight. If we digest red lead in acetic acid, we dissolve the protoxide, and leave the deutoxide untouched; it has a dark red colour, and is destitute of the beauty which characterizes red lead. Various experiments have been made to determine the additional quantity of oxygen necessary to convert the protoxide of lead into deutoxide. I made a set of experiments on the subject about twenty years ago;* but as I was not aware at that time, of the mixture of protoxide present in the pigment, I did not, of course, attempt to separate it, and consequently underrated the proportion of oxygen which it contained. Even Berzelius, though aware of the existence of the protoxide of lead in red lead, does not seem to have succeeded in removing the whole of it. But the proportion of oxygen, which he assigns to this oxide, though below the true quantity, affords a sufficient approximation to enable us to determine the composition of the deutoxide of lead.

9·835 parts of deutoxide, when heated to redness, gave out 0·29 parts of oxygen, and left 9·545 parts of protoxide of lead.† According to

* Nicholson's Jour. VIII. 289.

† Afhandlingar, III. 168, or Ann. de Chim. LXXVIII. 14. But there is a typographical error in the French translation.

this experiment deutoxide of lead is composed of

Protoxide of lead	9·545	or	14
Oxygen .	0·290	-	0·43

Atom of deutoxide of lead.

The following experiment, which I made with great care, will show that the true composition of deutoxide of lead is 14 protoxide + 0·5 oxygen. 29 grains of deutoxide of lead were digested in dilute, but pure nitric acid, till all action was at an end; the whole was then thrown on a double filter, and the peroxide of lead remaining undissolved was well washed and thoroughly dried in a temperature of nearly 500° —it weighed 15 grains. Hence it follows, that the protoxide dissolved by the acid weighed 14 grains. Thus, 29 grains of deutoxide of lead were resolved into

Protoxide of lead . .	14
Peroxide of lead . .	15
	29

But it will be shown immediately that 15 represents the atomic weight of peroxide, and that it is a compound of 1 atom lead and 2 atoms oxygen. Protoxide of lead is a compound of 1 atom lead and 1 atom oxygen: hence it follows, that 29 deutoxide of lead are composed of

2 atoms lead	= 26	or	1 atom lead	13
3 atoms oxgen	= 3	-	1½ atom oxygen	1·5
	29			14·5

Deutoxide of lead does not seem capable of entering into any chemical combination;—it is, therefore, in the present state of our knowledge, comparatively insignificant as a chemical substance.

3. The peroxide of lead is a flea brown coloured powder, which was discovered by Scheele. It may be obtained by digesting nitric acid on red lead. A portion of the deutoxide is reduced to the state of protoxide, and dissolves in the acid, while the oxygen given off by it uniting to another portion converts it into peroxide. If the deutoxide be pure, it is evident from the experiment stated above, that just one half of the lead is dissolved and the other half converted into peroxide. Atom of peroxide of lead.

I found long ago, that 100 grains of this oxide, when exposed to a red heat, left 91 grains of protoxide.* Now, if the 9 grains of loss be considered as oxygen, it will follow from this experiment, that peroxide of lead is composed of 100 lead + 18·34 oxygen, or of lead 13 + oxygen 2·384. But when I made these experiments I was not aware that metallic oxides are apt to retain water: the peroxide which I employed had been merely dried in the open air, and consequently, was not quite anhydrous. The loss of weight was partly water and partly oxygen;

* Nicholson's Journal, VIII. 288.

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consequently, my estimate of the quantity of oxygen in this oxide was too high.

Berzelius dried the peroxide of lead in a temperature at which tin melted. He found, that 5 parts of the oxide thus dried, lost, when exposed to a red heat, 0·325 parts;—the residue, which weighed 4·675 parts, being digested in acetic acid, left 0·13 parts of sulphate of lead and silica.* It follows from this experiment, that peroxide of lead is composed of

Protoxide of lead	4·545	or	14
Oxygen .	0·325	-	0·973
	4·87		

No doubt the true composition is

Protoxide of lead . .	14
Oxygen	1
	15

The atomic weight is 15, and the oxide is a compound of 1 atom lead = 13, and 2 atoms oxygen = 2.

Thus, the constituents of the three oxides of lead are as follows:

	LEAD.	OXYGEN.	ATOMIC WEIGHT.
Protoxide	1 atom	+ 1 atom . .	14
Deutoxide	1	+ 1½ . . .	14·5
Peroxide	1	+ 2 . . .	15

* Afhandlingar, III, 170., or Ann. de Chim. LXXVIII, 16. The French translation is unintelligible, because a sentence is left out.

4. When thin plates of pure lead are introduced into dry chlorine gas, the gas is gradually absorbed and the lead converted into a white matter, which is a chloride of lead. This chloride is easily obtained by mixing together solutions of nitrate of lead and of common salt: small brilliant crystals precipitate, which, when heated in a close vessel, melt and assume the form of a greyish matter, formerly distinguished by the name of *plumbum corneum*. I find, by a careful experiment, that 13 grains of lead, when converted into chloride, weigh 17·5 grains. Hence, it is obvious that this chloride is composed of Chloride of lead.

1 atom lead . .	13
1 atom chlorine . .	4·5
	17·5

SECT. III.

OF THE ATOMIC WEIGHT OF TIN.

Tin is a metal which forms two different oxides, when it combines with oxygen. The *protoxide* may be obtained by dissolving tin in strong muriatic acid (taking care to exclude all access of atmospheric air to the inside of the small retort in which the process is going on). When the muriatic acid is saturated with the tin, the liquid must Oxides of tin.

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be poured at once into a glass vessel containing as much caustic potash or soda as will saturate the whole muriatic acid in combination with the protoxide. A black powder falls, which is protoxide of tin; it may be separated by a filter, edulcorated and dried. When in combination with acids, this oxide has a great tendency to combine with more oxygen, and to be converted into peroxide; but when in a separate state, and dry, I have kept it for years in a common phial, without observing any alteration in its colour.

The peroxide of tin has a yellowish colour. It may be obtained by digesting tin in nitric acid, and gradually raising the temperature to redness. The acid is decomposed and driven off, while the peroxide of tin remains behind in a state of purity.

Both of these oxides form salts with muriatic acid; but my attempts to determine the atomic weight of tin, by a rigid analysis of these salts, did not succeed. The following experiment, however, which I have several times repeated, gives the composition of peroxide of tin, from which it is easy to deduce the atomic weight of this metal.

Atom of peroxide of tin.

7·25 grains of pure tin were put into a platinum crucible, and dissolved in a sufficient quantity of very dilute nitric acid. The solution was slowly evaporated to dryness, and the crucible gradually raised to a red heat. The peroxide of

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tin formed in this way weighed 9·25 grains; hence it is evidently a compound of

Tin	.	7·25
Oxygen	.	2
		9·25

But 2 denotes 2 atoms of oxygen; consequently, 7·25 must be the weight of an atom of tin. Peroxide of tin obviously weighs 9·25, and is a compound of 1 atom of tin and 2 atoms of oxygen.

Atom of protoxide.

2. The experiments of Berzelius* leave no doubt that the protoxide of tin contains just half the oxygen in the peroxide. It is, therefore, a compound of 1 atom tin and 1 atom oxygen, and its atomic weight is 8·25.

Chlorides of tin.

3. Tin combines with two proportions of chlorine, as well as of oxygen, and forms two chlorides. The protochloride is most easily formed pure, by amalgamating together tin and mercury, mixing the amalgam with a sufficient quantity of calomel; and exposing it in a glass tube to a heat at first low, but gradually raised high enough to expel all the mercury and the calomel. 7·25 grains of tin treated in this way, left 11·75 grains of protochloride. Hence this chloride is obviously composed of

* Nicholson's Journal, XXXV. 122.

1 atom tin . .	7·25
1 atom chlorine .	4·5
	11·75

This chloride is a grey matter, having a resinous lustre and fracture. When put into chlorine gas, it catches fire, and is converted into perchloride.

Fuming liquor of Libavius.

4. The perchloride of tin has been long known under the name of *fuming liquor* of Libavius. It may be obtained by mixing together amalgam of tin and corrosive sublimate, and distilling with a very moderate heat. A colourless liquid comes over at first, consisting chiefly of water; then the fuming liquor rushes all at once with such rapidity, that I have more than once lost the whole product of the distillation. Dr. John Davy found that this perchloride may be obtained likewise by mixing together concentrated permuriate of tin and sulphuric acid, and distilling with a gentle heat.

This perchloride gives out very copious and dense fumes when exposed to the air, in consequence of its great avidity for moisture. Adet found, that when three parts of it are mixed with one part of water, the whole condenses into a solid state. I see no reason to doubt that this perchloride, when in a state of purity, is a compound of 1 atom tin and 2 atoms chlorine; and that its atomic weight is 16·25;—but I have not

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been able to verify this opinion by direct analysis. I made three experiments upon fuming liquor of Libavius, prepared very carefully in my laboratory. The quantity of chlorine found in each did not exactly correspond; but the mean of all the three gave for the constituents of the chloride

1 atom tin . .	7·25
2¼ atoms chlorine	9·112
	16·362

The analysis of this compound by Dr. John Davy* gave very nearly the same result; or, rather, he found a somewhat greater proportion of chlorine, viz. 9·18 parts united to 7·25 of tin. It would seem from these analyses, that fuming liquor of Libavius, when prepared by means of amalgam of tin and corrosive sublimate, is apt to contain an excess of chlorine.

I find that permuriate of tin in crystals is composed of

1 atom peroxide of tin .	9·25
2 atoms muriatic acid .	9·25
3 atoms water . .	3·375
	21·875

When this salt is mixed with sulphuric acid, and

* Phil. Trans. 1812, p. 177.

distilled by a gentle heat, the perchloride obtained would probably be neutral; but I have not tried to prepare it in this way.

Sulphurets of tin.

5. The sulphurets of tin, which are two in number, likewise furnish decisive evidence of the atomic weight of tin.

The protosulphuret of tin may be obtained by melting together tin and sulphur in a glass tube, and keeping up the heat till the excess of sulphur is sublimed. When 7·25 grains of pure tin are thus converted into sulphuret, the weight of the new compound is 9·25. Hence it is a compound of

1 atom tin . .	7·25
1 atom sulphur .	2
	9·25

The persulphuret has been long known by the name of Mosaic gold. It is under the form of light scales, of a brownish yellow colour, and great beauty and lightness. It is soluble in nitromuriatic acid, and likewise in potash ley. The analysis of this sulphuret of tin by Dr. John Davy is sufficient to prove that it is a compound of

1 atom tin . .	7·25
2 atoms sulphur .	4
	11·25

for he found the constituents by analysis to be*

Tin	100	or	7·25
Sulphur	56·25	-	4·078

SECT. IV.

OF THE ATOMIC WEIGHT OF BISMUTH.

In order to determine the atomic weight of bismuth with accuracy, it is requisite to employ that metal in a state of purity. The bismuth of commerce is usually contaminated with iron, and almost always contains some sulphur. To obtain pure bismuth, I dissolved a quantity of the bismuth of commerce in nitric acid. The crystals of nitrate of bismuth being thrown into water, were decomposed, and a white powder, consisting chiefly of hydrated oxide of bismuth, fell to the bottom. This hydrate was well washed, dried upon the filter, and reduced to the metallic state, by heating it in a covered crucible with black flux.

1. Nine grains of bismuth purified in this way, were put into a platinum crucible, and dissolved in nitric acid. The solution was evaporated to dryness by a gentle heat, which was afterwards gradually raised till the crucible became percep- Atom of oxide of bismuth.

* Phil. Trans. 1812, p. 199.

tibly red hot. By this means, the acid was driven off, leaving behind it the bismuth reduced to the state of an oxide. It weighed exactly 10 grains, and consequently, the metal, when oxydized, had combined with one-ninth of its weight of oxygen. Hence, oxide of bismuth is composed of

Bismuth	9
Oxygen	1
	10

But 1 being the weight of an atom of oxygen, it is obvious that 9 must be the atomic weight of bismuth; and the atomic weight of oxide of bismuth is 10.

This metal combines with only 1 atom of oxygen, and forms only one oxide.

Chloride of bismuth.

2. The chloride of bismuth may be formed by mixing together bismuth in powder, with corrosive sublimate in a glass tube, and exposing the mixture to a heat, at first low, but gradually raised to the boiling point of mercury, or a little higher. The excess of corrosive sublimate and the reduced mercury, are gradually volatilized, leaving the chloride of bismuth in a state of purity. It is a solid substance, having a granular texture, a greyish white colour, and a silky lustre. I mixed 9 grains of pure bismuth in powder, with 40 grains of corrosive sublimate in a test tube. This test tube, with a cork fitted

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to it, was left for three or four days on the sand bath; at first the heat applied did not exceed that of boiling water, but the tube was brought gradually towards the hottest part of the sand bath, till the temperature was at last between 600° and 700°. Finally, it was raised high enough to drive off all the mercury and the corrosive sublimate which had escaped decomposition; the weight of the chloride of bismuth was within $\frac{1}{10}$th of a grain of 13·5 grains. The loss of $\frac{1}{10}$th of a grain, I ascribe to the volatilization of a small portion of the chloride, which it is very difficult to avoid. If we compare this experiment with the preceding, it will be obvious that the chloride of bismuth is a compound of

1 atom chlorine	4·5
1 atom bismuth	9
	13·5

Sulphuret of bismuth.

3. The atomic weight of bismuth deduced from the oxydation of the metal, is still farther confirmed by the sulphuret. This sulphuret occurs native, and may be easily formed artificially, by heating together bismuth and sulphur, and keeping up the heat till the excess of the sulphur is driven off. Nine grains of pure bismuth converted into a sulphuret in this way, in a green glass tube, became eleven grains of sulphuret, showing that the sulphuret is a compound of

1 atom bismuth	9
1 atom sulphur	2
	11

The previous analyses of sulphuret of bismuth by Dr. John Davy and Mr. Lagerhjelm almost coincide with this experiment of mine. Dr. John Davy * found it a compound of

Bismuth	9
Sulphur	2·007

M. Lagerhjelm obtained †

Bismuth	9
Sulphur	2·0268

Dr. John Davy's experiment was conducted nearly in the same way as my own: he employed 100 grains of bismuth—I presume the bismuth of commerce. Now, the presence of a very small portion of iron in this bismuth, would account for the slight excess of sulphur, which scarcely exceeds one third per cent. Lagerhjelm's analysis is not quite so near the truth as Dr. Davy's.

4. Vauquelin, in a set of experiments, published a number of years ago, upon the quantity of sulphur with which the metals combine when heated or fused with that substance, states that he found sulphuret of bismuth composed of ‡

* Phil. Trans. 1812. p. 200. † Annals of Philosophy, IV. 357.
‡ Ann. de Mus. d'Hist. Nat. XV. 9.

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Bismuth	68·25	or	9
Sulphur	31·75	-	4·186
	100·00		

If this sulphuret of Vauquelin exist, (for I have not succeeded in my attempts to form it artificially,) it is evidently a bisulphuret, or a compound of two atoms sulphur with one atom of bismuth.

SECT. V.

OF THE ATOMIC WEIGHT OF COPPER.

Oxides of copper.

Copper forms two oxides; the *red oxide*, which occurs native, and does not seem capable of combining with acids; and the *black*, which constitutes the basis of all the cupreous salts. It was shown long ago by Chenevix, and his experiments have been amply confirmed by succeeding researches, that the black oxide contains exactly twice as much oxygen as the red; and I shall show immediately, that if we reckon the weight of an atom of copper to be 4, then the composition of these oxides is as follows:

	COPPER.	OXYGEN.	
1. Red oxide	8	+ 1 or 2 atoms copper	+ 1 atom oxygen.
2. Black oxide	4	+ 1 or 1 atom copper	+ 1 atom oxygen.

I shall therefore distinguish the black oxide by

the name of *oxide of copper;* while to the red oxide we shall apply the term *suboxide*, indicating that it is a compound of two atoms copper and one atom oxygen. Such suboxides in general are incapable of constituting permanent salts with acids.

As the black oxide of copper constitutes the basis of all the cupreous salts, the knowledge of its atomic weight is of most importance in a chemical point of view. We may employ the common sulphate of copper, as a good instrument for determining the atomic weight of this oxide; because being manufactured to a considerable extent, and employed both in medicine and the arts, it may be easily procured in a state of purity. It has a fine blue colour, an exceedingly disagreeable cupreous taste, reddens vegetable blues, and crystallizes in oblique four-sided prisms, the faces of which are inclined to each other at angles of 124° and 56°.

Analysis of sulphate of copper.

1. When a solution of 15·625 grains of these crystals in water, is mixed with a solution of 13·25 grains of chloride of barium, a double decomposition takes place, sulphate of barytes precipitates, and the supernatant liquid is neither affected by sulphate of soda nor muriate of barytes. Hence, it follows, that 15·625 grains of this salt contain just 5 grains of sulphuric acid.

2. If the whole oxide of copper be precipitated from 15·625 grains of blue vitriol, and col-

lected without loss, it will weigh exactly five grains. This experiment is not easily made, because we have no good precipitant of oxide of copper. But I have accomplished it in various ways. If we throw down the oxide of copper by caustic potash, we obtain very nearly five grains, though I have never got the exact amount in this way. In general, the oxide of copper thus procured weighs about 4·9 or 4·95 grains. When the copper is thrown down by sulphuretted hydrogen, or by hydrosulphuret of ammonia, the precipitate, when collected without loss, and sufficiently dried, weighs 8 grains, and when dissolved in aqua regia, and precipitated by muriate of barytes, the sulphate of barytes obtained weighs 29·5 grains, indicating 10 grains of sulphuric acid, equivalent to 4 grains of sulphur; consequently, the copper in 15·625 grains of blue vitriol weighs exactly 4 grains.* This, coupled with the amount of the precipitate by means of caustic potash, leaves no doubt that the true weight of the oxide of copper in 15·625 grains of blue vitriol is 5 grains; and that it is a compound of

* If we precipitate the copper from 15·625 grains of sulphate of copper by means of a plate of zinc, taking care in the first place, to acidulate the solution of the salt with a little sulphuric acid, to prevent the copper from adhering to the zinc; the precipitated copper, if it be dried without allowing it to absorb oxygen, will weigh exactly four grains. This experiment is not easily made, because the copper while drying has a tendency to absorb oxygen But it is easy in this way to obtain a very near approximation.

Copper	4	or	1 atom
Oxygen	1	-	1 atom

3. The only other constituent of blue vitriol being water, it is obvious that the salt is a compound of

1 atom sulphuric acid	5
1 atom oxide of copper	5
5 atoms water	5·625
	15·625

Disulphate of copper.

4. There exists another sulphate of copper, which I formed by the following process: 31·25 grains of blue vitriol were dissolved in water in a retort, and the solution was mixed with 10 grains of peroxide of copper. The retort was put upon the sand bath in such a position that it was kept boiling several hours every day, taking care to add fresh water in proportion as that liquid was dissipated; and this was continued till all the oxide of copper had totally disappeared. This happened in about a couple of months; at the same time the liquid lost its blue colour, while a green coloured powder was deposited. The liquid being tested for copper by ammonia, was found to contain none. It is obvious, therefore, that the green powder contained all the acid and oxide of copper in 31·25 grains of blue vitriol, together with the additional 10 grains of oxide added. The green powder, therefore, was a compound of

Sulphuric acid	10	or	5
Oxide of copper	20	-	10

This powder was tasteless, insoluble in water, and produced no effect on vegetable blues. It was obviously a compound of 1 atom acid, and 2 atoms oxide, or it was a disulphate of copper.

5. Sulphuret of copper is easily formed by heating together copper filings and sulphur. The combination takes place suddenly when the mixture has reached a certain temperature, and the sulphur from being in a liquid state becomes suddenly solidified. This explains the reason of the ignition which takes place, and which attracted so much of the attention of the Dutch chemists. The first person who attempted to determine the composition of this sulphuret with the requisite precision was Berzelius. He found that 10 parts of copper, when converted into sulphuret, became 12·56 parts.* Now, 10 : 2·56 : : 8 : 2·048 ; so that according to this experiment, sulphuret of copper is composed of Disulphuret of copper.

Copper	8
Sulphur	2·048

The copper of commerce, which Berzelius probably employed in his experiment, is not quite pure. I believe it is often contaminated with some protoxide of copper, and always with some other

*Afhandlingar, III. 187.

metals. I prepared some very pure copper on purpose, and found that 8 grains of it, when converted into sulphuret in a green glass tube, became exactly 10 grains. Hence, it follows that this sulphuret is a compound of

Copper	8
Sulphur	2
	10

2 is an atom of sulphur and 8 is two atoms copper. So that this compound is a disulphuret of copper.

Sulphuret of copper.

Besides these two sulphurets of copper, a third seems to exist in combination with protosulphuret of iron; for M. Henry Rose found copper pyrites to be a compound of

Copper	34·4
Iron	30·47
Sulphur	35·87
	100·74
Silica	27
	101·01*

The excess of 1 per cent. was probably in the sulphur. But let us suppose the result to be exact, the above numbers are equivalent to

* Ann. de Chim. et de Phys. XXV. 197.

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Copper	4·000	or	1 atom
Iron	3·543	-	1 atom
Sulphur	4·170	-	2 atoms

It is obvious, that copper pyrites is a compound of

1 atom sulphuret of copper	6
1 atom sulphuret of iron	5·5
	11·5

Thus, there are three sulphurets of copper; namely,

	COPPER.		SULPHUR.	
1. Disulphuret composed of	2	atoms +	1	atom.
2. Sulphuret	1	atom +	1	atom.
3. Bisulphuret	1	atom +	2	atoms.

Atom of suboxide of copper.

6. If 100 grains of peroxide of copper be dissolved in muriatic acid, and 80 grains of copper filings be added to the solution, and the whole agitated in a well stopped phial nearly filled by the mixture, the copper filings are instantly dissolved without the evolution of any gas, and the liquid, which has become black and opaque, is found to contain a solution of suboxide of copper in muriatic acid. This experiment, for which we are indebted to Mr. Chenevix, but which I have frequently repeated, demonstrates the composition of suboxide of copper: for 100 grains of oxide of copper are composed of

Copper	80
Oxygen	20
	100

So that by the addition of 80 grains, the copper in the liquid is exactly doubled, while the oxygen with which it is combined remains the same as at first. Hence, suboxide of copper is obviously composed of

Copper	160	or	16	or	8
Oxygen	20	-	2	-	1

It is a compound of 2 atoms copper and 1 atom oxygen, and its atomic weight is 9.

Chloride of copper.

7. Chlorine and copper combine in two proportions, and form two chlorides analogous in their composition to the two oxides of copper.

The perchloride is easily obtained by dissolving peroxide of copper in muriatic acid, and concentrating the green coloured solution. Permuriate of copper is formed, and may be obtained in long four-sided rectangular prisms with square bases. This salt I find, by a careful analysis, is composed of

1 atom muriatic acid	4·625
1 atom oxide of copper	5
2 atoms water .	2·25
	11·875

When 11·875 grains of this salt are exposed to a temperature of between 400° and 500°, or indeed to a lower temperature, there is a diminution of weight amounting to exactly 3·375 grains, the green colour disappears, and an orange brown matter remains, weighing exactly 8·5 grains. Now, the 3·375 grains of matter driven off consist of pure water, as may be ascertained by performing the experiment in a retort, to which a receiver is luted. The water will come over into the receiver quite pure, unless too much heat has been applied. In that case some chlorine is apt to pass off, owing I presume to the agency of the common air in the retort.

3·375 grains of water is the equivalent for 3 atoms of that liquid; yet the salt contained only 2 atoms. The other atom of water was formed by the union of the atom of oxygen in the oxide with the atom of hydrogen in the muriatic acid. Thus the salt is changed into chloride of copper, which, as is obvious from the facts just stated, is a compound of

1 atom copper .	4
1 atom chlorine .	4·5
	8·5

8. The subchloride of copper was noticed by Boyle; and it has been minutely described by Prout, Chenevix, and Dr. John Davy. I have Subchloride of copper.

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not made any attempts to analyze it, because the previous analysis of Dr. Davy is perfectly accurate. He found it composed of

2 atoms copper	.	8
1 atom chlorine	.	4·5
		12·5

The constituents of the chlorides and sulphuret of copper, compared with those of the oxides, leave no room for doubt that the true atomic weight of this metal is 4.*

* It is hardly necessary to remark, that the atom of copper might be represented by 8, as well as by 4. In that case, red oxide of copper would be composed of

1 atom copper	=	8
1 atom oxygen	=	1
		9

and black oxide of

1 atom copper	=	8
2 atoms oxygen	=	2
		10

The chlorides would be:

protochloride	1 atom copper	=	8
	1 atom chlorine	=	4·5
			12·5
perchloride	1 atom copper	=	8
	2 atoms copper	=	9
			17

SECT. VI.

OF THE ATOMIC WEIGHT OF MERCURY.

It has been ascertained by unexceptionable experiments, that mercury combines with two doses of oxygen, and forms two oxides. The protoxide is *black*, and the peroxide *red*. The volatility of mercury and its compounds presents

Oxides of mercury

and the sulphurets:

protosulphuret of	1 atom copper	=	8
	1 atom sulphur	=	2
			10
bisulphuret of	1 atom copper	=	8
	2 atoms sulphur	=	4
			12
persulphuret of	1 atom copper	=	8
	4 atoms sulphur	=	8
			16

This was the idea I originally formed of these compounds, and it seems to be the one generally adopted by chemists. It was the consideration of the salts of copper that induced me to adopt 4 for the atomic weight of copper; for, if we represent the atom of copper by 8, all the salts of copper, without exception, will be bisalts, or will contain 2 atoms of acid, united to 1 atom of oxide. It was an object of some importance to get rid of this anomaly, which involved the salts of copper in a good deal of confusion. This was accomplished by adopting 4 for the atomic weight of copper, as had been already done by Dr. Wollaston and Dr. Prout.

a formidable obstacle to the rigid determination of their atomic weights.

Determined by Fourcroy,

1. Fourcroy, long ago, stated, that the protoxide of mercury is a compound of 100 metal and 4 oxygen; but, from the loose way in which this chemist was accustomed to express himself, we can consider this determination in no other light but that of a fortunate conjecture. Mr. Donovan, from a number of experiments on both oxides, has concluded that protoxide of mercury is composed of

Donovan,

Mercury	100	or	24·271
Oxygen	4·12	-	1*

And peroxide of

Mercury	100	or	25·575
Oxygen	7·82	-	2

The atomic weight of mercury, deduced from these two oxides, not being exactly the same, it is obvious that the experiments from which the constitution of these oxides has been deduced, are not quite exact. The mean of both gives us 24·923 for the atomic weight, which differs less than $\frac{1}{150}$th from 25, the atomic weight of mercury, deduced from the composition of protoxide of mercury, as stated by Fourcroy.

and Sefstrom.

M. Sefstrom made a set of experiments in Ber-

* Annals of Philosophy, XIV. 244.

zelius' laboratory on the composition of the oxides of mercury, with the results of which only I am acquainted.* He found the constituents of protoxide of mercury

Mercury	.	100	or	25·063
Oxygen	.	3.99	-	1

and those of red oxide

Mercury	.	100	or	25·031
Oxygen	.	7·99	-	2

If we take the mean of these two analyses, which do not exactly agree with each other, though they come much nearer than those of Donovan, we obtain 25·047 for the atomic weight of mercury, which exceeds 25 by less than $\frac{1}{500}$th part.

Now, as the atomic weight of mercury, as deduced from Donovan's experiments, is only a very little less than 25, while the same weight, deduced from the experiments of Sefstrom, is a very little more than 25, the inference from these experiments seems to be, that an atom of mercury weighs exactly 25.

2. The experiments of Donovan and Sefstrom leave no doubt that the oxygen in the peroxide of mercury is just double that in the protoxide. It is, therefore, composed of 1 atom mercury and 2 atoms oxygen; and its atomic weight is

* Annals of Philosophy, III. 355.

27, if we reckon the atomic weight of mercury 25. The truth of this is sufficiently established by the following experiment.

Experiments of the author.

27 grains of pure peroxide of mercury, prepared on purpose for the experiment, were put into an eight-ounce phial, and as much muriatic acid poured upon it as dissolved it completely. The phial was then placed upon the sand bath (having a charcoal stopper fitted into its mouth), and left till the liquid was evaporated to dryness. The phial was then covered about two-thirds up with sand, and the temperature was gradually raised sufficiently high to sublime the corrosive sublimate, into which the red oxide had been converted, as high as the middle of the phial. The phial, after being allowed to cool gradually, was weighed, and the weight of the corrosive sublimate was exactly 34 grains.

From this experiment it appears, that 27 peroxide of mercury form exactly 34 corrosive sublimate.

To understand this experiment it is necessary to know, that mercury combines with two proportions of chlorine, and forms two chlorides. The protochloride, usually denominated *calomel*, is a compound of 1 atom mercury and 1 atom chlorine; while the perchloride, or *corrosive sublimate*, is a compound of 1 atom mercury and 2 atoms chlorine.

With the knowledge of these facts, we may

now analyze the conversion of 27 grains of peroxide of mercury into 34 grains of corrosive sublimate.

27 peroxide are composed of — Atom of peroxide.

Mercury	.	25
Oxygen	.	2
		27

When muriatic acid is poured upon the 27 peroxide, two atoms of the acid, equivalent to 9·25 grains, unite with the oxide, forming a compound, which will amount to 36·25 grains, and be a compound of

1 atom peroxide	.	27
2 atoms muriatic acid		9·25
		36·25

When the solution is evaporated to dryness, the acid and peroxide mutually act upon each other: the oxygen of the oxide combines with the hydrogen of the acid, constituting 2 atoms of water, which are expelled by the heat; while the 2 atoms of chlorine combine with the 1 atom of mercury, and form a perchloride. Thus by the heat, the 36·25 of permuriate of mercury is resolved into

Oxygen	2	} constituting two atoms water.
Hydrogen	0·25	
	2·25	

Mercury	25	constituting an atom perchloride.
Chlorine	9	
	34	

It is clear, therefore, that 27 peroxide of mercury could not become 34 corrosive sublimate, unless the atomic weight of mercury were 25, and unless peroxide of mercury were composed of 1 atom mercury and 2 atoms oxygen.

Atom of mercury.

3. The analysis of calomel by Chenevix is so conclusive, that I did not consider it at first as worth while to make any researches on the subject. But it may be satisfactory to mention the following experiment, which was made with another object in view. A quantity of crystallized protonitrate of mercury, which I knew to contain precisely 25 grains of mercury, was dissolved in water, and the solution mixed with a solution of 7·5 grains of decrepitated common salt:—calomel precipitated, which, when collected on a double filter, washed and dried, weighed 29·5 grains; and the residual liquid being examined for mercury and muriatic acid, no traces of either could be detected. From this experiment it is obvious, that calomel is a compound of

Atom of calomel.

1 atom mercury	.	25
1 atom chlorine	.	4·5
		29·5

Analysis of cinnabar.

4. A careful analysis of cinnabar gave evi-

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dence equally satisfactory, that the atomic weight of mercury is 25. It will be proper to premise, in the first place, that the cinnabar which I employed was not quite free from traces of silica and peroxide of iron: but I made allowance for these bodies, and have left them out of the results to avoid complicated statements as much as possible.

Nitric acid has not the property of decomposing cinnabar, but nitromuriatic acid dissolves it with rapidity, when assisted by heat. 29 grains of cinnabar in powder were put into a retort, along with a sufficient quantity of nitromuriatic acid: the retort being placed on the sand bath, a pretty strong effervescence began, and the cinnabar disappeared in a few minutes, with the exception of a yellow matter, which was separated. This yellow matter was soft and ductile. When first collected, it weighed 3·46 grains; but being left a few days exposed to the air it became hard and brittle, and the weight was reduced to 3·2 grains. It was pure sulphur, burning all away with a blue flame without leaving any residue.

The nitromuriatic solution was supersaturated with carbonate of soda without the appearance of any precipitate. It was, therefore, evaporated nearly to dryness, redissolved in water, and mixed with a solution of caustic soda: the mercury precipitated in the state of brownish red flocks,

and being carefully collected and weighed, amounted to 27 grains very nearly.

The liquid, thus freed from mercury, was neutralized by nitric acid, and being mixed with nitrate of barytes, a precipitate of sulphate of barytes fell, which, after being washed, dried, and heated to redness, weighed 6 grains, equivalent to 0·81 grains of sulphur. Thus, we have obtained from 29 grains of cinnabar

Peroxide of mercury .	27
Sulphur . . .	4·01
	31·01

This exceeds the quantity analyzed by 2 grains. The reason is, that in the cinnabar the mercury is in the metallic state, while in the analysis it was obtained in the state of peroxide: but 27 peroxide are equivalent to 25 in the metallic state. Hence, cinnabar is a compound of

Mercury . .	25
Sulphur . .	4·01
	29·01

The 0·01 grain of excess is, doubtless, owing to an error in the analysis; which, with all my care, I was not able to avoid. But I consider the analysis as proving that cinnabar is a compound of

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1 atom mercury .	25
2 atoms sulphur .	4
	29

showing that 25 is the atomic weight of mercury.

The experiments related in this section, constitute the best of a very great number which I have made upon this difficult metal. They leave no doubt on my mind that the atomic weights of mercury and its compounds are as follows: Atomic weights of compounds of mercury.

	ATOMIC WEIGHT.		MERCURY.	OXYGEN.
Mercury	25			
Protoxide	26	.	1	+ 1 atom
Peroxide	27	.	1 atom	+ 2
				CHLORINE.
Protochloride	29·5	.	1	+ 1
Perchloride	34	.	1	+ 2
				IODINE.
Protiodide	40·5	.	1	+ 1
Periodide	56	.	1	+ 2

At the same time, it is proper to state, that I have made no attempts to analyze the iodides of this metal.

SECT. VII.

OF THE ATOMIC WEIGHT OF SILVER.

I HAVE already stated an experiment in page 105 of this work, from which the atomic weight of

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silver may be deduced. It was there mentioned, that when solutions of 21·5 grains of nitrate of silver and 7·5 grains of decrepitated common salt are mixed together, a curdy precipitate falls, and the residual liquid is neither affected by nitrate of silver nor common salt. It is evident from this experiment, that the silver in 21·5 grains of nitrate of silver, and the chlorine in 7·5 grains of chloride of sodium, just saturate each other.

Chloride of silver analyzed.

Now, 7·5 grains of chloride of sodium contain exactly 4·5 grains of chlorine. And, if 21·5 grains of nitrate of silver be cautiously heated to redness, the salt will be decomposed, the acid driven off, and the oxide reduced; the weight of silver remaining will be exactly (or at least very nearly) 13·75 grains. It is obvious from this, that the chloride of silver, formed by the mutual decomposition of 21·5 nitrate of silver and 7·5 chloride of sodium, must consist of

Silver . . .	13·75
Chlorine . . .	4·5
	18·25

Accordingly, when the precipitate is collected without loss, and after being well washed and dried is exposed to a heat sufficiently high to fuse it, the weight is exactly 18·25 grains.

Now, as 4·5 is the weight of an atom of chlorine, and as the chloride is neutral, it is obvious that 13·75 must represent the weight of an atom of silver. Atom of silver.

We have various analyses of the chloride of silver by preceding chemists; some of which it will be worth our while to state.

According to Dr. Marcet,* it is composed of

Chlorine	4·5
Silver	13·844

According to M. Gay-Lussac,* its constituents are

Chlorine	4·5
Silver	13·683

According to Berzelius,† it consists of

Chlorine	4·5
Silver	13·758

This determination of Berzelius differs from mine by only $\frac{1}{170}$th part, a quantity so small, that in almost every case of chemical analysis it may be neglected. I am almost ashamed to acknowledge the great number of times that I repeated this experiment before I could obtain what I considered as perfect accuracy. I began by employing the lunar caustic of commerce; Difficulties of the analysis.

* Annals of Philosophy, XII. 347. † Afhandlingar, III. 192.

but was constantly foiled. I then prepared nitrate of silver in platinum vessels, and found that it was anhydrous, and that 21·5 grains of it were just precipitated by 7·5 grains of chloride of sodium; but the weight of chloride obtained did not tally with the calculated weight. After many trials to discover the cause of the discordancy (for the chloride was always slightly deficient) I began to suspect that the distilled water which I employed might perhaps contain some ammonia, sufficient to dissolve a small portion of the chloride, and thus to occasion a deficiency, which became perceptible in consequence of the great quantity of that liquid with which it had been washed. This induced me to acidulate the water with a few drops of nitric acid in my next experiment. By this addition I found that the chloride of silver (as far as I could weigh it) amounted to just 18·25. The slight excess of chloride in the experiment of Berzelius, and the still greater excess in that of Marcet, the former amounting to 0·008 grain, and the latter to 0·094 grain, I ascribe to a minute portion of some muriate in the filter employed by these chemists. This could have no effect in my trials; because I employed just the quantity of nitrate of silver that was decomposed by 7·5 grains of common salt. Hence, my chloride was always deficient; and I had more than once given up the experiment as desperate be-

fore I thought of acidulating the water with nitric acid.

2. The preceding experiment gives us not only the atomic weight of silver, but enables us likewise to determine the atomic weight of oxide of silver; for it is obvious from it, that nitrate of silver is anhydrous, and that 21·5 grains of it contain exactly 13·75 grains of silver. Now, as the salt is neutral, and as 13·75 is equivalent to an atom of silver, it is obvious, that the 21·5 of the salt must contain an atom of nitric acid; and that the difference between 21·5 and 20·5, (viz. 13·75 6·7 5) must be the quantity of oxygen with which the silver is united. Hence, nitrate of silver is composed of

1 atom oxide of silver	of 1 atom silver	13·75	14·75
	1 atom oxygen	1	
1 atom nitric acid			6·75
			21·5

It is obvious, that the oxide of silver is a compound of 1 atom silver + 1 atom oxygen, and that its atomic weight is 14·75. Atom of oxide of silver.

3. When oxide of silver is dissolved in ammonia, and the solution left exposed to the air, a brilliant black pellicle collects on the surface. This pellicle was first examined by Mr. Faraday, from whose experiments it appears, that it contains two thirds of the oxygen in the common oxide of silver. My experiments on this pellicle, Suboxide of silver.

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which were made soon after Mr. Faraday had published his observations, were upon too small a scale. My object was merely to verify Mr. Faraday's statement; but as far as I went I obtained just the same results as had been stated by that chemist. This oxide then, which may be called a suboxide, would seem to be a compound of

1½ atom silver	=	20·625
1 atom oxygen	=	1
		21·625

This suboxide does not appear to form distinct salts with acids.

Sulphuret of silver.

4. The sulphuret of silver furnishes an additional evidence that the atomic weight of this metal is 13·75. This sulphuret, which is a black looking compound, possessed of some ductility, and quite sectile, may be formed by stratifying silver and sulphur in a covered crucible, and heating the mixture till the excess of sulphur is driven off. Berzelius made two experiments in this way.* In the first, 2·605 parts of silver became 2·993 parts of sulphuret. Here we have the sulphuret composed of

Silver	2·605	or	13·75
Sulphur	0·388	-	2·048

In the second, 10 parts of silver became 11·49

* Ann. de Chim. LXXIX. 131.

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parts of sulphuret. This sulphuret was composed of

Silver	10	or	13·75
Sulphur	1·49	-	2·0487

These experiments very nearly agree with each other; yet I am satisfied that the quantity of sulphur is somewhat overrated; it is difficult to say from what cause.

Vauquelin,* who formed the sulphuret of silver in the same way, found it composed of

Silver	100	or	13·75
Sulphur	14·59	-	2·0061

In this experiment, the excess of sulphur is only the eighth part of what existed in the sulphuret prepared by Berzelius.

Klaproth analyzed the native sulphuret of silver in the year 1793, at a time when minute accuracy in chemical analyses was not attempted. From 100 grains of the sulphuret, he obtained 112 grains of chloride of silver, equivalent to 84·383 grains of silver, and likewise 1½ grain of sulphate of silver, equivalent to 1·044 grain of silver.† From this analysis, it follows, that sulphuret of silver is composed of

Silver	85·427	or	13·75
Sulphur	14·573	-	2·3459
	100·000		

* Ann. de Mus. d'Hist. Nat. XVII. 16. † Beitrage, I. 162.

This result does not approach the truth so nearly by a great deal, as the synthetical experiments of Berzelius and Vauquelin.

In repeating these experiments, I found it much more difficult than I expected to procure absolutely pure silver. I found that silver which I had reduced from well washed chloride was not absolutely free from copper. The method which I ultimately adopted was to keep crystallized nitrate of silver in a state of fusion for some time. It was then dissolved in water, and precipitated by common salt. The precipitate was digested for some time in water acidulated with nitric acid. It was then thrown on a filter, and well washed with distilled water. Silver reduced from this chloride, and heated with sulphur, gave a sulphuret exceedingly near the theoretic proportions. As far as I could estimate the weight of sulphuret from 13·75 grains of silver, it amounted to 15·75 grains; certainly the weight was not so much as 15·76 grains. There can, therefore, be no doubt that sulphuret of silver is composed of

1 atom silver	=	13·75
1 atom sulphur	=	2
		15·75

Sulphate of silver.

5. I analyzed likewise the sulphate of silver, which corresponds in its constituents with the

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atomic weight of oxide of silver already deduced from the nitrate. Sulphate of silver is anhydrous, and its constituents are

Sulphuric acid	5
Oxide of silver	14·75
	19·75

Thus it appears certain that the atomic weight of silver, of its oxide, and its chloride, have been rightly stated. I have not examined the iodide, but see no reason to doubt that it is a compound of

1 atom iodine	15·5
1 atom silver	13·75
	29·25

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CHAP. XII.

OF THE ATOMIC WEIGHTS OF GOLD, PLATINUM, PALLADIUM, RHODIUM, AND IRIDIUM.

These five metals possess many peculiar characters. Their oxides are easily reduced to the metallic state by exposure to a red heat; they have little tendency to combine with acids and form salts: the consequence is, that we know very few saline compounds into which these oxides enter, with the exception of certain triple compounds, by means of which chiefly I have been enabled to determine the atomic weights of these metals, I trust with tolerable precision.

SECT. I.

OF THE ATOMIC WEIGHT OF GOLD.

It has been long known to all the world, that gold dissolves with facility in aqua regia; that the solution has a yellow colour, an astringent and very acrid taste; and that when sufficiently concentrated, it forms beautiful prismatic crys-

tals, which, however, are so very deliquescent, that I found it impossible to analyze them with even an approach to accuracy.

Analysis of triple chloride of gold and sodium.

But there is a triple salt of gold, which owes its formation to M. Chretien's attempt to introduce gold, or rather to revive the use of gold in medicine. Finding the muriate of gold too deliquescent for his purpose, he added a quantity of common salt to the muriatic solution, and then evaporated to dryness: the mass thus obtained did not deliquesce. Messrs. Figuier and Berard, on examining the mixture, detected the triple salt of gold to which I allude, described its properties, and even subjected it to analysis.* But as the results of their experiments do not furnish a very near approximation to the truth, I think it best to proceed at once to the experiments which I made on the subject, with a view of discovering the atomic weight of gold.

Preparation.

1. I employed in my experiments a very pure muriatic acid which I had myself prepared, and which was a compound of 40 parts real muriatic acid and 60 parts of water. I found that in order to dissolve 300 grains of gold, it was necessary to employ more than 277·5 grains of this acid. Now, the atomic weight of muriatic acid is 4·625; and 277·5 grains of the acid employed consisted of

* Jour. de Pharmacie, VI. 64.

Real acid	111
Water	166·5
	277·5

But 111 grains of muriatic acid are equivalent to 24 atoms: for 4·625 × 24 = 111. It will appear from the facts about to be stated in this section, that the atomic weight of gold is 25: and 300 = 25 × 12. So that 300 grains are equivalent to 12 atoms of gold.

From this it appears, that in order to obtain a solution of 12 atoms of gold, we must employ at least 24 atoms of muriatic acid. Hence, from this preliminary experiment, I considered it as probable, that muriate of gold is a compound containing 2 atoms muriatic acid for every atom of gold.

2. To the solution of 300 grains of gold in nitric muriatic acid, previously made as neutral as possible, 90 grains of pure decrepitated common salt were added, previously dissolved in water. On evaporating this solution, it crystallized readily, and I obtained fine crystals of the triple salt of gold to the very last drop. Not a single crystal of common salt separated; nor had even the last portions of the salt the least tendency to deliquesce. From this experiment, which was several times repeated, it is obvious, that the triple salt is a compound of 90 grains of common salt, and the quantity of muriate

of gold which 300 grains of gold are capable of forming.

But an integrant particle of chloride of sodium weighs 7·5 : and 7·5 × 12 = 90. From this it is evident, that 90 grains of decrepitated common salt are equivalent to 12 atoms of chloride of sodium ; and it has been stated that 300 grains of gold are equivalent to 12 atoms of that metal :—from this experiment it follows, that the triple salt contains just as many atoms of common salt as it does of gold.

3. The triple salt of gold crystallizes in long four-sided prisms. It has a beautiful orange colour, and is not in the least altered by exposure to the air; the description of its properties by Figuier is in general exact.

Analysis. I shall pass over a great many unsuccessful experiments which I made to determine the proportions of its constituents, and satisfy myself with describing the process, which was finally successful. Into a very small green glass retort, the weight of which had been previously ascertained and marked on it with a diamond, I put 50·5 grains of the crystallized triple salt, quite dry, but still retaining the whole water of crystallization ; the retort was placed on a choffer, and kept for two hours completely red hot, while its beak was plunged into a bason, over which was suspended an inverted glass jar filled with a solution of 55 grains of nitrate of silver

in distilled water. The salt melted and boiled, and was gradually deprived of its water; as soon as it became dry, chlorine gas was given out very rapidly at first, but more and more slowly, as the heating continued. This gas was absorbed by the nitrate of silver solution, and occasioned a precipitate of chloride of silver.

This experiment is attended by two difficulties, which it cost me some practice to obviate. The first is, the tendency which the liquid has to make its way into the red hot retort, in consequence of the absorption of the chlorine gas. This difficulty was obviated by having a contrivance for letting common air into the retort when the absorption began to threaten the destruction of the retort. The other difficulty is, the application of the requisite degree of heat to reduce the gold completely to the metallic state. Quite different from muriate of gold, this triple salt bears an incipient red heat with impunity, and it was not till after two or three failures that I became aware of the necessity of raising the fire as high as the glass would bear without melting, which was a distinct red heat, and keeping it up at least a couple of hours.

Three different successful experiments were made, with three different objects in view. In the first, I determined the weight of gold contained in 50·5 grains of the triple salt; in the second, the whole of the chlorine was combined

with silver, and the chloride of silver collected, washed, dried, fused, and weighed; in the third, I endeavoured to approximate as nearly as possible to the quantity of water of crystallization, by distilling it over into a small receiver. Perfect accuracy in this last experiment was not attempted, but merely such an approximation as enabled me to judge how far the quantity of water deduced from the other two experiments would be borne out by the analysis. I shall state at once the general result which was obtained.

The loss of weight which the salt sustained was 18 grains; one-half of this was chlorine, determined from the chloride of silver formed. This chloride, in two different experiments, weighed 36 grains, indicating 8·87 grains of chlorine. The small portion of chlorine gas remaining in the retort was estimated to weigh 0·13 grain; these two quantities together making 9 grains—the other 9 grains of loss were water. Of this I actually obtained 7 grains by the process above described; and by passing a current of air through the retort, and this through a solution of nitrate of silver, I satisfied myself that the weight of the residual chlorine gas did not exceed 0·13 grain. There can be no doubt, therefore, that the whole 9 grains were pure water. There remained in the retort 25 grains of gold. We see from paragraph 2d, that the

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true quantity of chloride of sodium was 7·5 grains; in general, the quantity actually obtained did not exceed 7·4 grains. Probably the 0·1 grain missing made its escape along with the water, owing to the rapidity with which the heat was raised, or to some other circumstance which I was not able to appreciate. I attempted to find it in the water; but the evidences were not sufficiently unequivocal to enable me to speak positively on the subject.

From the preceding analysis it appears, that 50·5 grains of the triple salt of gold are composed of

Gold . .	25
Chloride of sodium	7·5
Chlorine . .	9
Water . .	9
	50·5

Now, it is obvious that 7·5 is an integrant particle of common salt, 9 two atoms of chlorine, and 9 eight integrant particles of water. As the salt is neutral, and as all the other constituents enter into it in atomic proportions, gold must do so too; consequently, the atomic weight of gold is 25. It is obvious, therefore, that the constituents of the salt are as follows: Atom of gold.

Constituents.

1 atom bichloride of gold	= 34
1 atom chloride of sodium	= 7·5
8 atoms water . .	= 9
	50·5 *

Whether the gold and the sodium exist in this salt in the metallic state, or in the state of ox-

*M. Figuier has more recently published the result of a new analysis of this salt, which approaches exceedingly near what I have given in the text. Probably the small differences are owing to the different data from mine, according to which his calculations were made. He found the constituents as follows:

Bichloride of gold .	34·99
Chloride of sodium .	7·13
Water . . .	8·38
	50·50 †

Chloride of potassium likewise forms a triple salt, with the solution of gold. It crystallizes in prisms, is not altered by exposure to the atmosphere, and has a striking resemblance to the salt described in the text. It has been analyzed by M. Javal, who found the constituents to be

Chloride of gold .	68·64
Chloride of potassium .	24·26
Water . . .	7·10
	100·00

Probably it consists of

1 atom bichloride of gold .	34
1 atom chloride of potassium	9·5
4 atoms water . . .	4·5
	48

Javal's analysis does not agree very well with the preceding supposition. His quantity of chloride of potassium indicates very nearly 2 atoms. I have not myself made any experiments on this triple salt. See for Javal's Paper, Ann. de Chim. et de Phys. XVII. 337.

† Ann. de Chim. et de Phys. XIX. 177.

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ides, we have not data to determine, unless the presence of water of crystallization in the salt may be considered as a proof of the truth of the latter supposition. If these metals be in the state of oxides, then it follows, that the peroxide of gold, which the salt must contain, is a compound, not of 3 atoms oxygen and 1 atom gold, as Berzelius supposes, but of 2 atoms oxygen and 1 atom gold; for upon no other supposition can the products of the analysis be accounted for. No muriatic acid, but only chlorine, was disengaged from the salt. If the metals be oxydized, then the salt is composed of

2 atoms muriatic acid	= 9·25	}	36·25
1 atom peroxide of gold	= 27·00		
1 atom muriatic acid	= 4·625	}	8·625
1 atom soda . .	= 4·000		
5 atoms water . .			5·625
			50·5

Seems a chloride.

The great difficulty attending the decomposition of this salt by heat rather leads to the supposition, paradoxical as it may appear, that the gold in it is in the state of a bichloride. If that supposition be admitted as the most probable, then Berzelius' deduction, that peroxide of gold contains 3 atoms of oxygen, still retains its plausibility.

Oxides of gold.

If we adopt Berzelius' experiments on the

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oxides of gold, (and they have been confirmed by Javal,) then the atomic weight of the protoxide of gold will be 26, and of the peroxide 28.

Tritosulphuret of gold.

4. Sulphuret of gold, formed by pouring hydrosulphuret of potash into the muriate of gold, was analyzed by Oberkampf. He found it composed of

Gold	.	100	25
Sulphur	.	24·39	6·09

This approaches very nearly to 1 atom gold and 3 atoms sulphur. Doubtless the proportion of sulphur in this compound is overrated; for the sulphuret of gold cannot be dried by heat without being decomposed.* This analysis, therefore, serves to corroborate the atomic weight of gold as just determined.

Peroxide of gold.

5. Berzelius' analysis of the peroxide of gold is likewise very satisfactory. He deduced, from the quantity of mercury necessary to reduce a given weight of peroxide of gold, that it is a compound of

Gold	.	100	or	25
Oxygen	.	12·077	-	3·019

Had the quantity of oxygen been 12 grains, instead of 12·077, the coincidence would have been complete; but, considering the nature of

* Ann. de Chim. LXXX. 141.

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the experiment from which Berzelius deduced the proportion of oxygen in the peroxide, I rather think it surprizing that the coincidence is so great as it is. Javal actually analyzed the peroxide of gold, by heating it in a glass tube, and collecting the oxygen gas. He estimates the composition at gold 100, oxygen 11·909; but his estimate was founded on the specific gravity of oxygen gas as determined by Berzelius and Dulong, which I have shown in a former chapter to be too low. When we correct his estimate, the proportion of oxygen united to 100 gold turns out to be 12·0008,—a number which I am persuaded is almost exact.*

SECT. II.

OF THE ATOMIC WEIGHT OF PLATINUM.

Platinum dissolves, as every body knows, in strong nitromuriatic acid with effervescence. The solution has a dark brown colour, and is very astringent and corrosive. When concentrated by evaporation it does not crystallize, but forms a dark coloured dirty looking matter, not easily

* I have some suspicion that the true atomic weight of gold may ultimately turn out only 12·5 instead of 25. If that be the case, the triple salt analyzed in this section would be a compound of 2 atoms chloride of gold and 1 atom chloride of sodium. We have not data, at present, to determine this point with certainty.

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analyzed with accuracy. From the nitromuriatic solution of platinum it is easy to form triple salts by adding solutions of muriate of potash, muriate of soda, or muriate of ammonia. The triple salts with muriates of potash and ammonia are insoluble powders of a fine yellow colour: the triple salt with muriate of soda is soluble, and crystallizes in beautiful rhombic prisms. These salts furnish a method for determining the atomic weight of platinum, to which I had recourse, after a few unsuccessful trials with muriate of platinum.

Analysis of bichloride of platinum and potassium.

1. Triple muriate of platinum and potash is an insoluble yellow tasteless powder, and when properly dried contains no water of crystallization. After a number of preliminary trials to enable me to judge how I ought to proceed, and which it is unnecessary to detail, I analyzed the salt in the following manner:

30·5 grains of it were put into a platinum crucible, and subjected to a heat which was slowly and cautiously raised till the crucible became red hot: by this process the platinum was reduced to the metallic state, and the loss of weight sustained amounted to 9 grains,—it was owing to the escape of chlorine in the form of gas. If the salt has been overheated, (which happened in some of my first trials) the loss of weight will exceed 9 grains; but when this happens, the weight of the chloride of potassium

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remaining mixed with the platinum will be found just as much less than 9·5 grains, as that of the loss exceeds 9 grains. This gives us the cause of the excessive loss;—it is owing to the volatilization of a portion of that salt.

The matter remaining in the crucible, when the heat had been properly applied, weighed 21·5 grains: water was poured upon it repeatedly, and digested on it for some time, to dissolve off all the chloride of potassium. The platinum being then dried, was weighed, and its weight was found to amount to exactly 12 grains; consequently, the weight of the chloride of potassium was 9·5 grains. From this analysis it appears, that the triple salt is composed of

Platinum . . .	12
Chlorine . . .	9
Chloride of potassium .	9·5
	30·5

But the salt is neutral—9 indicates the weight of 2 atoms of chlorine, and 9·5 of an integrant particle of chloride of potassium: 12, therefore, must either be the weight of an atom of platinum, or at least, a multiple of it. From experiments to be stated immediately, it will be seen, that 12 represents the atomic weight of platinum. In the salt we find 1 atom of platinum combined with 2 atoms of chlorine, constituting a bichlo-

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ride. The constituents of the triple salt are obviously

1 atom bichloride of platinum	= 21
1 atom chloride of potassium	= 9·5
	30·5

And the atomic weight of an integrant particle of the salt is 30·5.

Berzelius has published an analysis of this powder, which differs but little from mine. He found the constituents

Platinum	40	or	12·2
Chlorine	29·2	-	8·906
Chloride of potassium	30·8	-	9·394
	100		30·5

The atomic weight of the salt is the same as that deduced from my own experiments. Not having seen the particulars of Berzelius' experiments, but merely the result, I cannot judge of the cause of the slight discrepancies between the proportions of the ingredient, when his analysis is compared with mine:—they are probably, in a great measure, owing to the difference of the data, which he employs for his calculations. But, notwithstanding these slight differences, the analysis of Berzelius is a most important corroboration of the very near approach to accuracy which I have attained in mine.

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2. The triple muriate of platinum and soda has not hitherto been described in any chemical book which I have seen—though it must have often been prepared by practical chemists. It may be worth while, therefore, to mention its most striking properties before proceeding to its analysis. Analysis of bichloride of platinum and sodium

Its colour is a fine orange red—it crystallizes in flat, and very oblique four-sided prisms—its taste is cooling, bitter, and disagreeable—it has no smell—its specific gravity is 1·980—at the temperature of 62°·5, 100 parts of water dissolve 107·2 parts of the crystals of this salt—it is soluble, likewise, in alcohol. I analyzed it in the following manner:

37·5 grains of the crystals being cautiously heated on the sand bath for about an hour, were found to sustain a loss of weight amounting, at an average, to 9 grains. Sometimes, when the heat happened to be too low, the loss of weight was less than 9 grains; and at other times when it was too high, it exceeded that amount. The salt, thus deprived of its water of crystallization, was heated to redness in a platinum crucible, and the heat was continued till the platinum in the salt was reduced to the metallic state: the additional loss of weight sustained was 9 grains—this loss was owing to the disengagement of chlorine. The matter remaining in the crucible was digested in distilled water till every thing soluble

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was taken up. The platinum now remaining in a state of purity, after being dried, weighed 12 grains; consequently, the weight of the chloride of sodium removed by the distilled water was just 7·5 grains. From this analysis it follows, that the triple muriate of platinum and soda is composed as follows:

Platinum . . .	12
Chlorine . . .	9
Chloride of sodium .	7·5
Water . . .	9
	37·5

In one portion of this salt which I examined, the water, instead of 9 grains, amounted only to 8·31 grains, which would indicate only 7½ atoms of water instead of 8 atoms. The cause of this difference I am unable to explain:—perhaps the salt had been accidentally deprived of a portion of its water.

The constituents of this salt give us 12 for the atomic weight of platinum, precisely like that of the preceding salt. We may either consider it as composed of

1 atom bichloride of platinum	= 21
1 atom chloride of sodium .	= 7·5
8 atoms water . . .	= 9
	37·5

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Or, its constituents in the crystallized state may be

1 atom bipermuriate of platinum	= 23·25
1 atom muriate of soda . .	= 8·625
5 atoms water	= 5·625
	37·5

The constituents, which ever supposition we adopt, are the same; the only difference consists in the way in which they are arranged. If the salt be a permuriate, 3 atoms of the water must go to convert the platinum and sodium into oxides, and the 3 atoms of chlorine into muriatic acid.

3. Ammonio-muriate of platinum is formed by mixing sal-ammoniac with a concentrated solution of muriate of platinum. This salt is soluble in water, though very slightly, and it crystallizes in small grains seemingly octohedrons. Its colour is a rich yellow, and it contains no water, but is composed of

Analysis of ammonio-muriate of platinum.

2 atoms chlorine	9	21
1 atom platinum	12	
1 atom sal-ammoniac . . .		6·75
		27·75

The preceding analyses are sufficient to show that 12 either denotes the atomic weight of platinum, or that it is a multiple of that weight. Some other compound of platinum is still want-

ing to enable us to decide which of these two suppositions is the true. After some unsuccessful attempts, I at last found that the sulphate of platinum put it in my power to solve the problem.

4. I formed a quantity of sulphate of platinum by the process pointed out by Mr. Edmund Davy.

Analysis of sulphate of platinum.

19 grains of this dry sulphate were put into a small green glass retort, and exposed to a red heat till the platinum was reduced to the metallic state; it weighed exactly 12 grains. This experiment was repeated several times, in order to collect the oxygen gas evolved by the reduction of the platinum, and to determine the quantity of sulphuric acid separated; for both these products could not be conveniently collected at the same time. The oxygen gas evolved was rather less than three cubic inches, and amounted, therefore, very nearly to 2 grains. The sulphuric acid was a very little less than 5 grains; the reason was, that a little sulphurous acid was disengaged, which I found it difficult to obtain without some loss. From these experiments it is obvious enough, that the constituents of sulphate of platinum are

Platinum	12
Oxygen	2
Sulphuric acid	5
	19

Now the salt was neutral, and 5 being equiva-

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lent to an atom of sulphuric acid, it follows that 12 must denote an atom of platinum: 2 being equivalent to 2 atoms of oxygen, it is obvious that the oxide of platinum in the sulphate, which is the peroxide, is a compound of 1 atom platinum and 2 atoms oxygen. Consequently, its atomic weight is 14.

Atom of platinum.

Atom of peroxide.

The knowledge of the atomic weight of platinum deduced from this salt, enables us to decide, that the triple chlorides of platinum and potash, and platinum and soda, contain 1 atom of platinum united to 2 atoms of chlorine.

Mr. Edmund Davy made an analysis of the sulphate of platinum, a good many years ago, and his results, though not quite accurate, constitute near approximations to the truth. It was his analysis that pointed out to me the mode which I had to follow. My method being nearly the same with his, I considered it unnecessary to describe it minutely. Mr. E. Davy's results are as follows:*

Platinum	12·4697
Oxygen	1·5352
Sulphuric acid	4·9951
	19·0000

The weight of an integrant particle of the salt deduced from this analysis is the same as from my own, namely 19. The proportion of sulphuric

* Phil Mag. XL. 354.

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acid is very nearly correct; but the platinum is too much, while the oxygen is as much too little, as if the metal had not been completely reduced to the metallic state.

Peroxide of platinum.

5. I tried to prepare a quantity of peroxide of platinum by the process pointed out by Berzelius. Finding it to contain both muriatic acid and an alkali, I reduced it to a fine powder, and boiled it for a week in a flask kept nearly full of distilled water. After this treatment, the proportion of salt which it contained was so exceedingly small, that I am disposed to consider the characters which my powder possessed, as very nearly those of pure peroxide of platinum. Its colour was a brownish black; it was tasteless, insoluble in nitric, sulphuric, oxalic, and acetic acids; but it dissolved, though slowly, and not without considerable boiling, in muriatic and phosphoric acids. I made no attempt to analyze it, both because it was not absolutely pure, and because I was not sure whether it was perfectly anhydrous.

Amalgam of platinum.

6. Conceiving that the amalgam of platinum was likely to throw some light on its atomic weight, I made a quantity of it by triturating platinum powder and mercury in a mortar; beginning with a few grains of each, and adding additional portions of both metals as the amalgamation proceeded. The fluid amalgam thus formed was put into a leathern bag, and subjected to strong pressure in

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order to squeeze out all the uncombined mercury. I obtained a solid brittle amalgam, having the colour of mercury, a granular texture, and a brittle consistency. 61 grains of this amalgam were exposed to a heat at first moderate, but gradually raised as much as possible in a wind furnace, and kept up for half an hour. The loss of weight sustained was 24·9 grains, and there remained 36·1 grains of platinum apparently pure. Now, 24·9 is very nearly 25, which denotes the atomic weight of mercury; and 36·1 is also exceedingly near 36 = 3 atoms of platinum. It is obvious from this, that the amalgam was a compound of

3 atoms platinum	36
1 atom mercury	25
	61

Conceiving that by allowing the fluid amalgam of platinum to crystallize, I should probably obtain a compound of the two metals in a different proportion, I placed a quantity of the fluid amalgam on an inclined plane, and when it had become solid by the running off of the superfluous mercury, I analyzed it in the way just described, and found its constituents to be

Platinum	12
Mercury	35·3

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It is obvious that the crystals had retained a portion of the mercury mechanically lodged between their particles. In fact, these crystals resembled crystals of a salt taken out of the mother liquor before being dried; yet I think it not unlikely from this experiment, that the crystals of amalgam of mercury, if they could be obtained in a state of purity, would consist of

1 atom platinum	12
1 atom mercury	25
	37

7. From the preceding experiments there seems no doubt that the atom of platinum weighs 12; and that it forms two oxides, only one of which, the peroxide, has been yet obtained in a separate state. The atomic weight of the peroxide is 14. The protoxide must be a compound of 1 atom platinum and 1 atom oxygen, and its atomic weight must be 13.

SECT. III.

OF THE ATOMIC WEIGHT OF RHODIUM.

The soda-muriate of rhodium, a triple salt discovered by Dr. Wollaston, and with a quantity of which he was so obliging as to supply me a

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good many years ago, enabled me to determine the atomic weight of rhodium and its oxides, with considerable precision. This salt forms rhomboidal crystals of an intensely deep red colour, and not altered by exposure to the air. It is insoluble in alcohol, but sufficiently so in water. Carbonate of ammonia produces no effect upon the solution of this salt; but caustic ammonia, as well as the caustic fixed alkalies precipitate the peroxide of rhodium in yellow coloured flocks. An excess of the fixed alkalies redissolves the whole of the precipitate. Though ammonia does not act so powerfully as a solvent, yet it is not without its effect; for the whole oxide of rhodium is never obtained if an excess of ammonia be added to the solution.

Analysis of soda muriate of rhodium.

1. A hundred grains of crystals of soda muriate of rhodium were dissolved in water, and the peroxide was precipitated by ammonia, taking care not to add that alkali in excess. The oxide of rhodium, when collected, washed, and dried, was found to weigh 26·07 grains.

Into a solution of another 100 grains of the same salt a polished plate of zinc was put, and left in the solution till the whole of the rhodium which it contained had been precipitated in the metallic state. To prevent the rhodium from adhering to the zinc, which would have made it difficult to weigh it correctly, the liquor had been acidulated with some muriatic acid. The

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weight of the metallic rhodium obtained in this experiment was 19·1 grains.

From this preliminary experiment it appears, that 26·07 grains of yellow oxide of rhodium contain 19·1 grains of metallic rhodium, and consequently, 6·97 grains of oxygen: therefore, yellow oxide of rhodium is a compound of

Rhodium	19·1	or	5·486
Oxygen	6·97	-	2

I was induced to infer from this experiment, that the atomic weight of rhodium is 5·5; and that the yellow oxide is a compound of 1 atom of rhodium, and 2 atoms of oxygen; and consequently weighs 7·5.

2. 28·625 grains of the crystals of soda-muriate of rhodium were put into a small green glass retort, and exposed to a heat which was gradually raised to an incipient redness, and kept up a considerable time in order to dissipate completely the aqueous vapours which are disengaged from the salt by the heat. This experiment cannot be made in a metallic vessel without disengaging some muriatic acid, and reducing a portion of the rhodium to the metallic state; but I have kept the salt in a low red heat for upwards of an hour in a green glass retort, and found it still perfectly soluble in water with the usual dark red colour, and consequently, still retaining the whole of its acid. The loss of

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weight in this experiment was 9 grains; which is, therefore, the water of crystallization in 28·625 grains of soda-muriate of rhodium.

3. 28·625 grains of soda-muriate of rhodium were dissolved in water, and precipitated by ammonia added very cautiously, and all excess avoided. The yellow oxide obtained weighed 7·5 grains.—This step of the analysis cost me a great deal of trouble, and was repeated about ten times before I succeeded in separating the whole of the oxide, and collecting it without loss.

4. The residual liquid, from which the oxide of rhodium had been thrown down, was evaporated with great caution to dryness, and the residual salt weighed. The weight did not exactly agree in the different trials; doubtless, because I applied the heat so cautiously that the whole aqueous portion was not driven off; but the average weight of this saline residual was 14·5 grains. It was a mixture of common salt and sal-ammoniac. Being exposed to a heat sufficient to drive off the sal-ammoniac, the residual common salt weighed 7·5 grains. Consequently, the loss of weight was 7 grains; but the weight of an integrant particle of sal-ammoniac is 6·75 grains; for it is composed of

1 atom muriatic acid	4·625
1 atom ammonia	2.125
	6·75

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It is obvious that the 0·25 grain of loss, over and above this integrant particle of sal-ammoniac, must have been water. Now, the 4·625 grains of muriatic acid, in the 6·75 grains of sal-ammoniac volatilized, must have existed in the 28·625 grains of the soda-muriate of rhodium, and must have been in combination with the oxide of rhodium.

From the preceding analysis it appears, that soda-muriate of rhodium is a compound of

Yellow oxide of rhodium	7·5
Muriatic acid . .	4·625
Common salt . .	7·5
Water . . .	9·0
	28·625

Atom of peroxide of rhodium.

Now, this salt is perfectly neutral: 9 represents eight atoms of water; 7·5 is an integrant particle of chloride of sodium; and 4·625 an integrant particle of muriatic acid. 7·5 therefore, must represent the weight of an integrant particle of yellow oxide of rhodium. The constituents of the soda-muriate of rhodium may therefore be represented as follows:

1 atom permuriate of rhodium	12·125
1 atom muriate of soda .	8·625
7 atoms water . .	7·875
	28·625

For one of the atoms of water separated by heat,

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was in all probability formed by the change of the integrant particle of muriate of soda into chloride of sodium.

5. The preceding analysis, when compared with the preliminary experiment, leaves no doubt that the weight of an atom of rhodium is 5·5, and that the yellow oxide is a compound of 1 atom rhodium and 2 atoms oxygen. Atom of rhodium.

This oxide of rhodium is described by Berzelius as *brown;* but when obtained by precipitation from the soda-muriate of rhodium, it is always *yellow.* When exposed to heat it becomes slowly *brown,* and at last *black.* During this change of colour, I could detect no escape of moisture, to induce me to suppose that the yellow coloured powder is a hydrate, and the brown the anhydrous oxide. Whether the brown oxide be the same, or different from the yellow, I have not ascertained; most probably it is a mixture of the yellow and the black oxides. The black oxide is undoubtedly the protoxide of rhodium, and a compound of 1 atom rhodium and 1 atom oxygen; so that its atomic weight is 6·5. Oxides of rhodium.

If the brown powder should appear, upon farther examination, to be a peculiar oxide, it is obvious that it must be a compound of 1 atom rhodium and 1½ atom oxygen; and that its atomic weight must be 7. I did not succeed in my attempts to dissolve it in acids; but this insolu-

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bility may have been owing to the heat to which it had been exposed.

SECT. IV.

OF THE ATOMIC WEIGHT OF PALLADIUM.

My stock of palladium was so small, that I was under the necessity of making my experiments upon a very minute scale. This precluded the possibility of attaining the mathematical accuracy necessary for determining the atomic weight with certainty; but as my experiments, so far as they go, confirm those already made by Berzelius on this metal, I flatter myself that the number which I have deduced from them is a very near approximation to the truth. From the great scarcity of this metal at present, it is unlikely that quantities sufficiently large to decide the point with certainty, will speedily be at the disposal of any chemist.

1. Palladium, as is known, dissolves in all the acids; but by far the best solvent of it is nitro-muriatic acid: the solution has a very deep red colour. When we evaporate the solution to dryness, and re-dissolve the residual salt in water, the colour of the liquid is a reddish brown; its taste is intensely astringent, without any accompanying flavour of a disagreeable nature.

Properties of muriate of palladium.

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This solution is precipitated by potash in *dark red* flocks; by ammonia in *buff coloured* flocks. The precipitate by potash readily dissolves in nitric acid; but the ammoniacal precipitate does not dissolve in that acid till the action of the acid is assisted by heat. Gallic acid gives the liquid a *greenish brown* colour, but occasions no immediate precipitate; prussiate of potash throws down *reddish brown* flocks, but the solution is not rendered colourless.

Muriate of palladium has a reddish brown colour. It does not crystallize; its taste is intensely astringent. When the dry salt is exposed to the air, it becomes moist on the surface, but does not flow into a liquid. This salt dissolves readily in water.

Potash muriate of palladium.

2. I dissolved 7 grains of palladium in muriatic acid (assisted by a little nitric acid). To the solution I added a quantity of carbonate of potash, which I knew to contain exactly 6 grains of potash. This solution being evaporated, yielded crystals of triple muriate of palladium and potash to the very last drop. This experiment shows, that in the triple salt the palladium bears to the potash the ratio of 7 to 6.

Oxide of palladium.

3. Berzelius has given us the result of two experiments which he made with palladium. He oxydized 100 parts of palladium, by heating them in a platinum crucible, with some potash and nitre; the oxide weighed 114·209 parts.

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As palladium forms only one oxide, we may consider it as a compound of 1 atom metal and 1 atom oxygen. Now,

14·209 (the oxygen which united with the metal) : 100 (the weight of metal) : : 1 (atomic weight of oxygen) : 7·038 = atomic weight of palladium.

Sulphuret of palladium.

He informs us likewise, that 100 parts of palladium, when converted into sulphuret, combine with 28·15 parts of sulphur. If we consider the sulphuret thus formed as a compound of 1 atom metal and 1 atom sulphur, we obtain 7·104 for the atomic weight of palladium; for

28·15 : 100 : : 2 (atom of sulphuret) : 7·104. *

These two separate estimates of the atomic weight of palladium approach so nearly to 7, that I was led from them to consider 7 as the true atomic weight of this metal. It was this that induced me to make choice of 7 grains of palladium, and to add to the muriatic solution 6 grains of potash, both of these quantities being equivalent to the atomic weight of these bodies. The result of the experiment shows that the opinion was correct, or very nearly so, and authorizes us to make choice of 7 as the true atomic weight of palladium. It would have been desirable to have made the experiment upon a larger scale—to have employed, for example,

* Essai sur la Theorie des Proportions Chimiques, p. 137.

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70 grains of palladium and 60 grains of potash. Such quantities would have shown more decisively whether there was an excess of either of the ingredients; but, unfortunately, my stock of palladium was inadequate to any such experiment.

4. The triple muriate of palladium and potash crystallized in very small needles, of a most beautiful brown colour. Dr. Wollaston describes them as four-sided prisms; and says, that when viewed transversely, they are of a bright green; but when seen in the direction of their axes, they are dark red. In my crystals, from their extreme minuteness, it was impossible to observe these appearances. Was the brown colour owing to a mixture of the two colours described by Wollaston? Potash muriate of palladium.

It has an intensely astringent taste, accompanied with a perceptible sweetness. It is insoluble in alcohol, but pretty soluble in water; and the solution has a dark red colour, like that of muriate of palladium. It contains very little water; for 10 grains of it, when kept 24 hours upon the sand bath, in a temperature of nearly 600°, lost only 0·12 grain of weight. When heated to redness the salt melted, and I kept 10 grains in a state of fusion for half an hour; the loss of weight was 0·8 grain. When exposed to the intense heat of a wind furnace, the palladium is reduced to the metallic state; but the tem-

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perature requisite for this reduction is so high, that the greatest part of the muriate of potash is volatilized. The weight of palladium obtained from 10 grains of the triple salt was 3·08 grains.

Now, it was shown by a preliminary experiment, that the potash in this salt bears to the palladium the ratio of 6 to 7; consequently, 10 grains of the salt must contain 2·64 grains of potash.

The palladium in the salt is doubtless in the state of oxide. If the atomic weight of palladium be 7, and that of oxide of palladium 8, then (since 7 : 8 : : 3·08 : 3·52,) 3·52 grains must be the weight of oxide of palladium in 10 grains of the triple salt.

Both of these bases in the triple salt are combined with muriatic acid. Now, the atomic weight of muriatic acid being 4·625, it is evident that 8 grains of oxide of palladium will be just saturated by 4·625 grains of muriatic acid; and 3·52 grains of oxide will require for saturation 2·035 grains of muriatic acid.

And, since 6 potash require 4·625 of muriatic acid, 2·64 grains of potash must require for saturation 1·526 grain of muriatic acid.

From this it appears, that 2·035 grains of muriatic acid are in combination with the oxide of palladium, and 1·526 grain with the potash.

These calculations enable us to state the con-

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stituents of the triple muriate of palladium as follows:

Oxide of palladium	3·52	5·555 muriate of palladium.
Muriatic acid	2·035	
Potash .	2·64	4·166 muriate of potash.
Muriatic acid	1·526	
Water . . .	0·279	
	10·000	

This estimate would give us the constitution of the salt in atomic numbers as follows:

1 atom muriate of palladium	=	12·625
1 atom muriate of potash	=	10·625
$\frac{3}{5}$ths of an atom water .	=	0·675
		23·925

Had the quantity of water amounted to 1 atom instead of $\frac{3}{5}$ths of an atom, the analysis would have been more satisfactory.

The reader will observe that with respect to palladium, I was obliged to rest satisfied with the preliminary experiments which I made on the other metals, before attempting the analysis from which the atomic weights are deduced. These preliminary trials I have thought it needless to state in the other sections; but my stock of palladium having been exhausted by them, I was under the necessity of drawing my conclusions respecting this metal from them entirely. The above analysis, (if analysis it can be called)

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was thrice repeated with very nearly the same result.

Chloride of palladium.

5. I made three attempts to ascertain the atomic weight of palladium, by forming a chloride. My method was to dissolve 7 grains of palladium in muriatic acid, to evaporate the solution to dryness, and to expose the muriate to heat in a covered platinum crucible.

The first trial gave	11·910	grains of chloride
The second .	12·133	
The third .	12·231	
Mean . .	12·091	

These weights are too high, if 7 be the atomic weight of palladium; for if we subtract 7 from 12·091, the remainder is 5·091, which somewhat exceeds the weight of an atom of chlorine. Perhaps the salt was not exposed to a heat sufficiently high to decompose the muriate completely. The experiment is scarcely susceptible of accuracy; because at the heat necessary to decompose the muriates, a portion of the chlorine is apt to escape.

The preceding experiments, imperfect as they are, lead to the conclusion, that the atomic weight of palladium is 7, and that of its oxide 8. These numbers are certainly very near the truth.

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SECT. V.

OF THE ATOMIC WEIGHT OF IRIDIUM.

I PREPARED a quantity of muriate of iridium from the black matter which remains when crude platina is dissolved in nitro-muriatic acid. The process which I followed was nearly that pointed out by Vauquelin in his paper on osmium and iridium. This black matter was found to contain a very considerable proportion of iron and some titanium; the quantity of iridium which it yielded was much less than I had anticipated.

1. Muriate of iridium crystallizes in tetrahedrons; it has a great deal of lustre, and a brown colour so deep that the salt appears black. Its taste is intensely bitter and astringent; its solution in water has a red colour, so deep that the liquid continues opaque even after it has been a good deal diluted with water. When so much diluted as to be transparent, the colour appears yellow. Properties of chloride of iridium.

The aqueous solution of muriate of iridium is rendered colourless by the addition of a few drops of any of the following bodies:

Gallic acid,
Prussiate of potash,

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2. A hundred grains of the crystals were put into a small green glass retort, and kept red hot for two hours by means of a charcoal fire. The crystals did not alter their appearance in the least; yet they emitted a perceptible smell of chlorine, and the salt sustained a loss of weight amounting to 2·625 grains. The crystals thus treated were completely soluble in water; they were therefore in a state of a pure anhydrous chloride of iridium. Analysis of chloride of iridium.

3. 82·5 grains of this chloride dried in a red heat were put into a platinum crucible, and exposed to the strongest heat which I could raise in a wind furnace. When the crucible was cold, I found that the chloride had been decomposed, and that there remained 37·5 grains of metallic iridium. The loss of weight sustained was therefore 45 grains, and this loss was obviously occasioned by the dissipation of the chlorine.

This experiment will be more easily understood if we divide the quantity of chloride employed by ten. 8·25 grains of chloride of iridium, when decomposed by heat, lose 4·5 grains of chlorine, and the remaining 3·75 grains consist of metallic iridium. Thus we see that the chloride is composed of

Iridium . . .	3·75
Chlorine . . .	4·5
	8.25

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Atom of iridium.

Now, as 4·5 is equivalent to an atom of chlorine, 3·75 must represent the atomic weight of iridium.

I repeated this experiment twice, employing each time 8·25 grains of chloride of iridium; because my stock of salt had been too much exhausted by the preceding trials to allow me to employ a greater quantity. These two experiments did not quite agree with each other; the first leaving a greater quantity of iridium than 3·75 grains, and the second a smaller quantity: the mean of the two made the quantity of iridium amount to 3·88 grains. This approaches as near to 3·75, the atomic weight deduced from the first experiment, as could be expected, when we take into view the very small scale on which the experiments were made. For when we employ in our trials very small quantities of matter, exact results are not to be looked for; because the unavoidable inaccuracies arising from weighing, or from want of absolute correctness in the weights which we employ, bear too great a proportion to the whole quantity used. But the first experiment, which was made with great care upon a quantity sufficiently great for accuracy, gives us, I conceive, the true atomic weight of iridium.

I believe the crystals usually called muriate of iridium should be called chloride of iridium; for the loss of weight being only 2·625 per cent.,

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does not amount to quite so much as the fifth of an atom of water. This explains the reason why the iridium is not precipitated by alkalies, as is usually the case with metallic oxides.

When the solution of this salt in water is made without heat, it has a fine green colour; but if we boil the green liquid, it gradually loses its original colour and becomes red. This change of colour has been generally ascribed to the addition of oxygen to the oxide of iridium. It has been concluded from it that there are two oxides of iridium,—the protoxide is *green* and the peroxide *red*. Whether this explanation be the true one I have not been able to determine, as all my attempts to obtain the oxides of iridium in a separate state have ended in disappointment. If there be two oxides of iridium, the protoxide is doubtless composed of 1 atom iridium and 1 atom oxygen, and its atomic weight must be 4·75. Peroxide of iridium must be a compound of 1 atom iridium and 2 atoms oxygen, and its atomic weight must be 5·75.

Oxides of iridium.

SECT. VI.

OF THE ATOMIC WEIGHT OF OSMIUM.

I AM still unacquainted with the atomic weight of osmium—the quantity of that anomalous sub-

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stance at my disposal being too small to enable me to prosecute the subject to any extent.

1. I mixed together equal weights of zinc filings and osmium, and putting the mixture into a glass tube bent like a retort, I poured on it a quantity of dilute sulphuric acid, to see whether the hydrogen gas evolved contained any osmium in solution: but I could obtain no evidence that it contained any. The gas had no sensible smell nor taste; it was not absorbed by water, and did not produce any sensible effect upon the solutions of lead. It burned just like common hydrogen gas, and required, as usual, half its volume of oxygen gas for complete combustion.

The sulphuric acid solution of the zinc was black and opaque, and contained, obviously, a portion of the osmium in a state of solution. But upon attempting to obtain this triple solution in a dry state, the colour gradually became lighter as the evaporation advanced, and when the whole had been reduced to dryness, all traces of the presence of osmium had vanished.

Osmium, in the metallic state, was digested in caustic soda ley:—a yellow coloured liquid was obtained, but the greatest part of the osmium remained undissolved.

END OF VOLUME FIRST.

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FIRST PRINCIPLES OF CHEMISTRY.

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Ut potero, explicabo; nec tamen ut Pythius Apollo, certa ut sint et fixa, quæ dixero: sed, ut homunculus, probabilia conjecturâ sequens.

Tusc. Quæst. Lib. I. c. 9.

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AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES

OF

CHEMISTRY

BY

EXPERIMENT.

By THOMAS THOMSON, M. D.,

REGIUS PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GLASGOW; F. R. S. LONDON AND EDINBURGH; FELLOW OF THE LINNÆAN SOCIETY; OF THE GEOLOGICAL SOCIETY; OF THE CAMBRIAN SOCIETY FOR THE ENCOURAGEMENT OF GEOLOGY, MINERALOGY, AND NATURAL HISTORY; OF THE IMPERIAL MEDICO-CHIRURGICAL AND PHARMACEUTICAL SOCIETIES OF ST. PETERSBURGH; OF THE ROYAL ACADEMY OF SCIENCES OF NAPLES; OF THE MINERALOGICAL SOCIETY OF DRESDEN; OF THE MINING SOCIETY OF FRANKFORT ON THE MAINE; OF THE CÆSARIAN NATURAL HISTORY SOCIETY OF MOSCOW; OF THE LITERARY AND PHILOSOPHICAL, AND NATURAL HISTORY SOCIETIES OF NEW YORK; &c.

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AN ATTEMPT

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CHAP. XIII.

OF THE ATOMIC WEIGHTS OF URANIUM, ANTIMONY, CHROMIUM, MOLYBDENUM, TUNGSTEN, COLUMBIUM, AND TITANIUM.

The seven metallic bodies, which I propose to treat of in this chapter, form compounds with oxygen, which possess rather the properties of acids than of bases. The peroxides of three of them, viz. chromium, molybdenum, and tungsten, are well marked acids, for they form neutral salts with the bases, which are (several of them) capable of crystallizing. The peroxides of the other four are not so decidedly acid; but they exhibit a much greater tendency to unite with bases than with acids, and the oxides of tantalum and titanium are found native always united with bases.

SECT. I.

OF THE ATOMIC WEIGHT OF URANIUM.

It is sufficiently known, that uranium was discovered by Klaproth, in a set of experiments which he made on black blende, in 1789; that the properties and some of the compounds of uranium were examined by Bucholz, about the beginning of the present century; and that M. Schönberg made a set of experiments in Berzelius' laboratory in 1813, in order to determine its atomic weight. But by far the most elaborate and instructive investigation of the properties of uranium and its compounds was made by M. Arfwedson, and inserted by him in the Memoirs of the Stockholm Academy of Sciences for 1822. By the kindness of Mr. Heuland of London, whose liberality I have so often experienced, I was supplied with a sufficient stock of pitchblende, to enable me to procure the oxides of this metal in such quantities as put it in my power to repeat such of Arfwedson's experiments as seemed to require examination, and to determine the atomic weight of these compounds, I trust, with considerable accuracy.

Method of obtaining peroxide of uranium.

Pitchblende obviously varies considerably in its composition, consisting, in fact, of a variety

of minerals mechanically mixed. Galena and copper pyrites may be occasionally observed interspersed through it. Arfwedson informs us that he found in it arsenic, cobalt, and zinc, in addition to the iron, and copper, and lead which had been noticed by Klaproth. In the specimens of pitchblende which I examined I could find no traces of arsenic, cobalt, or zinc; but copper and iron existed in abundance, and likewise some lead. My method of obtaining the peroxide of uranium was the following: The pitchblende was reduced to powder, and digested in nitric acid till every thing soluble was taken up. The solution was rendered as neutral as possible by evaporation. A current of sulphuretted hydrogen gas was then passed through it till every thing precipitable by that means was thrown down. The precipitate was at first dark brown, and it always retained that colour to the very end; not the least appearance of any thing yellow (to lead to the suspicion of the presence of arsenic) could be detected. The solution, thus freed from copper and lead, was filtered, and, after being heated to drive off the sulphuretted hydrogen, was precipitated by caustic ammonia. The precipitate thus obtained was washed and separated on the filter; and, while still moist, was digested in a pretty strong solution of carbonate of ammonia. A fine lemon yellow solution was obtained; and there remain-

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ed a red insoluble matter, consisting chiefly of iron, which was not particularly examined. The solution in carbonate of ammonia being set aside for a few days in a close vessel, a considerable number of very fine rich yellow crystals were deposited, consisting of four-sided right prisms, with rectangular bases. This salt was tasteless, and insoluble in water, and proved, on examination, to be a compound of carbonate of ammonia, percarbonate of uranium, and water. It was analyzed in the following manner:

Analysis of ammonio-carbonate of uranium.

1. 49·875 grains of the crystals were put into a small retort, and exposed to a heat not exceeding 400°, on the sand bath. There first came over some moisture, and then carbonate of ammonia sublimed. I did not succeed in weighing the water and the carbonate of ammonia separately, for the carbonate absorbed the whole of the water, and became dry crystals; but the total loss of weight sustained by the salt was 18 grains. The salt, by being thus deprived of its carbonate of ammonia and water, had acquired a most beautiful orange red colour. It still dissolved in acids with effervescence, and therefore contained carbonic acid. When strongly heated by a spirit lamp, some water was disengaged, and some carbonic acid (mixed probably with oxygen gas) and the peroxide of uranium was converted into protoxide. It now consisted of black grains, having considerable lustre. They were easily

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reduced to powder, and the powder had a dark green colour. The weight of the protoxide thus obtained was 27 grains; so that the loss of weight was 4·875 grains.

The 18 grains which sublimed first I consider to consist of

3 atoms carbonate of ammonia	14·625
3 atoms water . .	3·375
	18

By dissolving the matter in water, and mixing the solution with muriate of lime, I found by the weight of the precipitate that the carbonate of ammonia was very nearly 14·625 grains. The 4·875 grains, driven off by a red heat, I consider as composed of

1 atom oxygen . .	1
1 atom carbonic acid .	2·75
1 atom water . .	1·125
	4·875

If these suppositions be admitted, the triple salt was a compound of

3 atoms carbonate of ammonia	14·625
1 atom percarbonate of uranium	30·75
4 atoms water . .	4·5
	49·875

From this analysis it is clear that an atom of

Atom of uranium and its oxides.

peroxide of uranium weighs 28, and an atom of protoxide 27; hence the atomic weight of uranium in the metallic state must be 26.

2. It has been long known that uranium combines with two proportions of oxygen, and forms two oxides. Before proceeding farther, it will be proper to give some account of these oxides; because none of the chemical books which I have seen contain any thing on the subject.

Protoxide of uranium.

(1.) Protoxide of uranium, obtained by exposing the percarbonate of uranium and ammonia to a red heat, is composed of small grains, having a black colour, and a good deal of lustre; but when reduced to powder, it has a dark green colour. It is soluble in muriatic and sulphuric acid; but the solution goes on very slowly, except when the oxide is in the state of a hydrate. The solutions are green, and the protoxide is thrown down in the state of a brown coloured hydrate, which dissolves very easily in acids, forming a dark green solution. In nitric acid the protoxide dissolves very readily with the evolution of nitrous gas; and by this solution it is converted into peroxide. The protoxide of uranium is tasteless, and not altered by exposure to the air. It combines readily with the acids; all its salts have a green colour, and none that I have tried is capable of crystallizing.

Peroxide of uranium.

(2.) Peroxide of uranium has, I suppose, a lemon yellow colour,—at least this is the colour

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by which most of its salts are distinguished. Such is its tendency to combine with other bodies that it seems impossible to obtain it in a separate state. It dissolves with ease in nitric acid, and forms a lemon yellow solution of great intensity, which crystallizes and forms the nitrate of uranium in fine lemon yellow crystals, having the form of right four-sided prisms with square bases. If we throw down the oxide from this salt by caustic ammonia or soda, it retains these alkalies in combination, from which it cannot be freed by washing. If we throw it down by carbonate of ammonia, we obtain a yellow powder, which is most frequently a percarbonate of uranium; but sometimes, a triple salt composed of carbonate of ammonia and percarbonate of uranium. If we throw it down by potash or soda, we obtain a beautiful orange red powder, which is a triple compound of percarbonate of uranium and an alkaline carbonate. Arfwedson has shown, that if we mix together solutions of pernitrate of uranium and any earthy or metallic nitrate, and add caustic ammonia or potash to the solution, the peroxide of uranium precipitates in chemical combination with the earthy or metallic oxide present.

Thus it appears, that peroxide of uranium is capable of uniting both with acids and with bases; so that it performs the double function of an alkali and an acid. None of the simple

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salts into which it enters as a base crystallizes except the nitrate; but it forms many crystallizable triple salts. I have examined

Persulphate of uranium and potash,
Permuriate of uranium and potash,
Percarbonate of uranium and ammonia,

all of which crystallize very well.

Action of reagents on pernitrate of uranium.

I shall here mention the action of various reagents upon pernitrate of uranium.

1. Prussiate of potash—A dark red brown precipitate, somewhat similar to that of prussiate of copper.
2. Gallic acid or infusion of galls—O, if the salt contain an excess of nitric acid; but if neutral, the precipitate thrown down is very similar to that produced by prussiate of potash.
3. Carbonate of soda—A light yellow precipitate, redissolved by an excess of the carbonate; again precipitated on heating the liquid.
4. Caustic soda—A yellow precipitate, redissolved by an excess of the alkali. [Was this owing to the presence of carbonate of soda? Arfwedson says it is not redissolved by the caustic alkalies.]
5. Caustic ammonia—A fine lemon yellow precipitate, not redissolved by an excess of alkali.
6. Carbonate of ammonia—A yellow precipitate, redissolved by an excess of the carbonate: solution, lemon yellow.
7. Chromate of potash—A fine orange precipitate of great intensity.
8. Phosphate of soda—A yellowish white precipitate.
9. Arseniate of soda—A white precipitate, with a slight yellow tinge.

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10. Tungstate of soda—A yellow precipitate.
11. Tartrate of potash—O.
12. Oxalate of potash—O.

Arfwedson says, that peroxide of uranium is slightly soluble in water. Not having been able to procure the oxide in a separate state, I was unable to determine the point; but I found it impossible, by washing, to deprive the percarbonate of uranium of the property of giving a greenish yellow colour to water: hence, I conceive that salt to be slightly soluble in water.

Reduction of uranium.

3. M. Arfwedson passed a current of dry hydrogen gas over hot protoxide of uranium, and by this means reduced it to the metallic state. The metal thus obtained was in crystals, having nearly the form of regular octahedrons: they had a strong metallic lustre and a reddish brown colour. This metal may be exposed to the air in ordinary temperatures without alteration; but when heated, it undergoes a kind of combustion, and is converted into protoxide of uranium. Arfwedson made two experiments to determine how much loss protoxide of uranium sustains when converted in this way into metallic uranium. He found that

1·187	protoxide	lost	0·042
1·468	———	—	0·052

According to these experiments, 100 parts of uranium combine, in order to be converted into

protoxide, with the following proportion of oxygen:

By first experiment, with	3·66812
By second experiment, with	3·67231
Mean . . .	3·670215

He made two other experiments, the reverse of the preceding. A quantity of metallic uranium was exposed to a red heat in an open vessel: by this means it was converted into protoxide, and the increase of weight was determined. These experiments were as follows:

(1.) 0·636 uranium absorbed, 0·0235 oxygen.
(2.) 1·006 - - 0·0375

According to these experiments, 100 uranium, when converted into protoxide, combines with

By first experiment .	3·69497 oxygen
By second experiment .	3·72763
Mean . . .	3·71130
Mean of first set .	3·670215
Mean of the whole .	3·690757

This last mean, being the result of four careful experiments made in different ways, may be considered to come as near the truth as can be expected by that mode of experimenting. Let us see the atomic weight of uranium which results

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from this number :—If protoxide of uranium be a compound of 1 atom oxygen and 1 atom uranium, we have

3·690757 : 100 : : 1 : 27·095 = atomic weight of uranium.

This is a little higher than 26—the result which I obtained from the analysis of the triple salt described above. If 26 be the true atomic weight of uranium, as I think it is, then 100 parts of this metal, when converted into protoxide, should combine with 3·8461 parts of oxygen, which is only a little higher than Arfwedson's last result. Indeed, I conceive it to be almost impossible to come to the exact truth by Arfwedson's methods. I have repeated the whole of his experiments with great care; but my results differ fully as much from each other as the difference between 3·73 and 3·84 : and some of my results gave the quantity of oxygen as high as 3·84.

Arfwedson's experiments to determine the atom of peroxide of uranium.

4. M. Arfwedson made a set of experiments likewise, to determine the quantity of oxygen in peroxide of uranium, which I shall state before giving an account of those which I myself made with the same object in view.

(1.) He formed uraniate of lead by mixing together solutions of permuriate of uranium and muriate of lead, and mixing the liquid with caustic ammonia. A yellow precipitate fell, consisting of the two oxides chemically combined.

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He found by analysis that this salt was a compound of

Peroxide of uranium	0·9912
Protoxide of lead	1·3088
	2·3000

When 2·3 parts of this salt in an anhydrous state were decomposed by hydrogen gas, the water evolved weighed 0·164, containing 0·14577 oxygen. Now, by this process, both the oxides were reduced to the metallic state: 1·3038 of protoxide of lead contain 0·0935 oxygen, which subtracted from 0·14577 leaves 0·0522 for the quantity of oxygen contained in 0·9912 peroxide of uranium. It is easy from these data to deduce the quantity of oxygen contained in 100 parts of peroxide of uranium:—it is obviously 5·2663 parts. So that peroxide of uranium is composed, according to this experiment, of

Uranium	100
Oxygen	5·559

Another experiment was made with another portion of uraniate of lead composed of

Peroxide of uranium	1·086725
Protoxide of lead	0·173275
	1·260000

The water obtained weighed 0·0785, equivalent to 0·0697 oxygen; of this oxygen 0·012377 be-

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longed to the protoxide of lead, the remainder, amounting to 0·0574, existed in the peroxide of uranium. It follows from these data that the peroxide of uranium is a compound of

Uranium	100
Oxygen	5·5765

The mean of these two results gives us the constituents of the peroxide as follows:

Uranium	100
Oxygen	5·56775

Now, if the atomic weight of uranium be 26, and if the peroxide be a compound of 1 atom metal and 2 atoms oxygen, its constituents would be

Uranium	100
Oxygen	7·6923

The preceding experiments do not correspond with this supposition. They agree more nearly with the notion that the peroxide of uranium contains $1\frac{1}{2}$ atom of oxygen:—for on this supposition, its constituents would be

1 atom uranium	26	or	100
$1\frac{1}{2}$ atom oxygen	1·5	-	5·76923
	27·5		

This somewhat surpasses the result obtained by Arfwedson, but not very much.

(2.) He formed uraniate of barytes by mixing together solutions of permuriate of uranium and muriate of barytes; caustic ammonia being added, the uraniate of barytes precipitated. It was hastily washed on a filter with boiling water, to prevent the precipitation of carbonate of barytes; it was then dried and heated to redness, to render it anhydrous. Two experiments were made with two different preparations of uraniate of barytes. I shall state the results of each.

First. 1·343 of uraniate of barytes gave 0·295 sulphate of barytes, equivalent to 0·195 barytes. The protoxide of uranium obtained from the same salt weighed 1·121 ; now,

Barytes . .	0·195
Protoxide of uranium	1·121
	1·316

The difference between 1·316 and 1·343 is 0·027, which must be the oxygen driven off when the peroxide of uranium was converted into protoxide. But 1·121 : 0·027 : : 100 : 2·4085. It appears from this experiment that 100 protoxide + 2·4085 oxygen = 102·4085 peroxide.

Second. 1·456 uraniate of barytes gave 0·364 sulphate of barytes, equivalent to 0·2406 barytes, and 1·186 protoxide of uranium. The difference between these weights united, and that of the uraniate is 0·0294, which must be

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the oxygen driven off when the peroxide of uranium was converted into protoxide. Now, 1·186 : 0·0294 : : 100 : 2·4789. It appears from this experiment that 100 protoxide + 2·4789 = 102·4789 peroxide.

The mean of these two experiments gives us peroxide of uranium composed of

Protoxide of uranium	100
Oxygen . . .	2·4437

Now, if the protoxide of uranium be a compound of 26 uranium + 1 oxygen, it is obvious that 100 parts of it must contain 96·2963 uranium and 3·7037 oxygen ; and peroxide of uranium must be a compound of

Uranium	96·2963	or	100
Oxygen	6·1474	-	6·3839
	102·4437		

The proportion of oxygen in the peroxide of uranium, found by the analysis of this salt, exceeds considerably that obtained from the analysis of uraniate of lead. Though it does not amount to two atoms, it exceeds $1\frac{1}{2}$ atom, being very nearly $1\frac{2}{3}$ atom.

(3.) M. Arfwedson analyzed the potash sulphate of uranium in the following manner : 2·172 parts of the anhydrous salt were dissolved in water, and precipitated by muriate of barytes. The sulphate of barytes obtained weighed 1·814

parts, equivalent to 0·6149 sulphuric acid. The filtered liquid was mixed with caustic ammonia to get rid of the peroxide of uranium; sulphuric acid was then added, partly to separate any barytes which it might contain, and partly to saturate the potash. The liquid was then evaporated to dryness, and being heated to redness to drive off the ammoniacal salt, there remained 0·533 parts of pure sulphate of potash, equivalent to 0·2907 potash. Thus he obtained the sulphuric acid and the potash in the salt, and he concluded that the deficit of weight was peroxide of uranium. The constituents of the salt then are

Sulphuric acid .	0·6149	or	28·311
Potash . .	0·2907	-	13·384
Peroxide of uranium	1·2664	-	58·305
	2·1720		100

Now, 13·384 potash are saturated by 11·153 of sulphuric acid. There remain 17·158 of sulphuric acid, which in the salt must have been united with 58·305 of peroxide of uranium.

M. Arfwedson having obtained this result, calculates the quantity of oxygen in the 58·305 parts of peroxide of uranium from a canon of Berzelius; namely, that 100 parts of sulphuric acid saturate a quantity of basis containing 20 parts of oxygen. From this canon it is obvious, that 17·158 parts of sulphuric acid must saturate a quantity of basis containing 3·4316 oxygen.

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This would give us peroxide of uranium composed of

Uranium	54·8734	or	100
Oxygen	3·4316	-	6·254
	58·3050		

But this canon of Berzelius is correct only when the basis is a protoxide, and when the salt is neutral, or a compound of 1 atom sulphuric acid and 1 atom base; for sulphuric acid is capable of combining with bases in various proportions. Sometimes 1 atom of the base unites with 2 atoms of sulphuric acid. Bisulphate of potash is a salt of this kind. In it the potash, combined with a 100 parts of the acid, contains only 10 parts of oxygen instead of 20. Sometimes 1½ atom of sulphuric acid combines with 1 atom of base; such combinations I distinguish by the name of sesquisulphates.—The sesquisulphate of potash (did it exist) would be a compound of such a nature, that the oxygen in the potash, combined with 100 sulphuric acid, would contain only 15 parts of oxygen.

As peroxide of uranium contains certainly more than 1 atom of oxygen, the canon of Berzelius cannot apply to it. As the triple salt, analyzed by Arfwedson, reddens vegetable blues even after having been fused, there is a presumption that it contains more than 1 atom of sulphuric acid united with 1 atom of peroxide of

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uranium. I shall show immediately that it contains 1½ atom of sulphuric acid united to 1 atom of peroxide of uranium. Let us see, therefore, what the atomic weight of peroxide of uranium will be, if we consider 17·158 as representing 1½ atom of sulphuric acid, and 58·305 as representing 1 atom of peroxide of uranium. It is obvious, that two-thirds of 17·158 or 11·439 must in that case represent 1 atom of sulphuric acid. Now, 11·439 : 58·305 : : 5 : 25·486 = atomic weight of peroxide of uranium. This is somewhat under the truth, as will appear immediately; though it would have been very difficult to have come nearer by Arfwedson's method of analysis; for a portion of the peroxide of uranium precipitates with the sulphate of barytes. This caused him to overrate the quantity of sulphuric acid, and consequently to underrate, by at least as much, the peroxide of uranium in the salt.

5. I shall now relate the experiments which I made on this salt.

Analysis of potash persesquisulphate of uranium by the author.

The peroxide of uranium which I employed to prepare it was in the state of carbonate. It had been thrown down from nitric acid by carbonate of ammonia, and I could not discover any ammonia in it, either by the smell or by any other reagent, when it was digested with caustic potash. Its constituents, by the most careful analysis of it which I could make, appeared to be

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1 atom carbonic acid .	2·75
1 atom peroxide of uranium	28·00
1 atom water . .	1·125
	31·875

I took 318·75 grains of this carbonate (equivalent to 10 atoms peroxide of uranium) and poured over it 183·75 grains of sulphuric acid of the specific gravity 1·847 (equivalent to 30 atoms acid) and a considerable quantity of water, and digested the mixture on the sand bath till a complete solution was obtained. I thus employed twice as much acid as the requisite quantity. The reason was, that the solution goes on very slowly unless there be an excess of acid. To this solution I added 110 grains of sulphate of potash (equivalent to 10 atoms of the salt) previously dissolved in water, and evaporated the mixture. The triple sulphate was deposited to the very last from this solution n a state of purity, without any crystals of sulphate of potash ever appearing, showing clearly that in the triple salt there exists just an atom of each basis. When the liquid was reduced to a very small quantity, I was obliged to employ a higher temperature to continue the evaporation. The consequence was, that at last the salt began to acquire a greenish tinge. This effect was doubtless owing to the redundant sulphuric acid present. On account of this change,

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the 40 or 50 grains of the salt, obtained at the end of the process, were not employed in the experiments to be immediately described.

The salt thus obtained was redissolved, and evaporated a second time. It was obtained partly in the state of small crystalline grains, and partly in hard globular crystals, composed of small needles diverging from a centre; but the form of the crystals was too irregular to be determined. This salt has a most beautiful lemon yellow colour. Its taste is very astringent, like that of all the salts of uranium; but it leaves likewise an impression of bitterness.

(1.) 51 grains of these crystals were exposed to a pretty strong heat (but not quite red heat) in a platinum crucible. The process was stopped when fusion seemed to be beginning—the reason of this was, that in some previous trials I had found that if the salt had been exposed to a strong red heat, and had been completely fused, it was not afterwards altogether soluble in water. The loss of weight by this regulated heat was exactly 4·5 grains, which is equivalent to 4 atoms water; from this experiment it follows, that 51 parts of the triple salt contain 4 atoms of water.

(2.) 51 grains of the crystals of the same salt were dissolved in water, and the solution was mixed with a solution of 33·125 grains of chloride of barium. A double decomposition took

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place; and after the sulphate of barytes had precipitated, the clear liquid was tested with glauber salt and with muriate of barytes, but did not become in the least muddy by the addition of either, showing that it contained no sensible quantity of barytes or sulphuric acid; but $33{\cdot}125 = 13{\cdot}25 \times 2{\cdot}5$. Consequently, 51 grains of the salt contain 12·5 grains of sulphuric acid, which is equivalent to $2\frac{1}{2}$ atoms of that acid.

(3.) 51 grains of crystallized salt were dissolved in water, and mixed with an excess of ammonia, which precipitated the peroxide of uranium in yellow flocks. The whole was thrown upon a filter, and the peroxide was washed repeatedly with caustic ammonia, till it was judged to be freed completely from all admixture of sulphate of potash. This method was employed, because it was found, that when pure water was used to wash the peroxide of uranium, a portion of it was redissolved. The liquid which passed through the filter was evaporated to dryness in a platinum vessel, and then the whole was heated to redness to expel all the ammoniacal salt: the residual salt was white, with a scarcely perceptible shade of yellow; it weighed 11·2 grains. Being redissolved in water and mixed with ammonia, a few yellow flocks were precipitated, which being collected on a filter and dried, weighed, as nearly as could be determined, exactly 0·2 grain: the salt possessed the

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character of pure sulphate of potash. Thus it appears, that 51 grains of the crystallized compound salt contain exactly 11 grains of sulphate of potash.

(4.) I did not attempt to determine the weight of the peroxide of uranium. As it was precipitated it contained a quantity of ammonia united to it. By exposure to a heat, very nearly but not quite so high as a red heat, I drove off most of the ammonia, if not the whole of it; by which the peroxide was deprived of its yellow colour, and assumed a fine red with a shade of brown; and 31·8 grains, by this treatment, were reduced to 28 grains. Hence, I consider the yellow precipitate as a compound of

1 atom peroxide of uranium	28
1 atom ammonia . .	2·125
1½ atom water . .	1·6875
	31·8125

The matter driven off consisted partly of ammonia and partly of water; but it would have been difficult to have determined the proportions of each.

(5.) From the above analysis, which was made with the most scrupulous care, it follows, that 51 grains of the crystallized compound salt of uranium contained the following constituents:

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4 atoms water . .	4·5
1½ atom sulphuric acid .	7·5
1 atom sulphate of potash	11
	23·0
Deficiency . .	28
	51

This deficiency must consist of peroxide of uranium; consequently, 28 must represent the weight of an atom of peroxide of uranium; and the compound salt must consist of

1 atom sesquisulphate of uranium	1½ atom acid	7·5	35·5
	1 atom oxide	28	
1 atom sulphate of potash . . .			11
4 atoms water			4·5
			51

Analysis of persesquinitrate of uranium.

6. The combination of nitric acid and peroxide of uranium crystallizes very easily in large flat four-sided rectangular prisms. Its colour is a fine lemon yellow—its taste is astringent and acid, and it reddens vegetable blues, even after having been three times dissolved in pure water and crystallized—it is exceedingly soluble both in water and alcohol—it melts in its water of crystallization when exposed to a moderate heat.

(1.) 57·25 grains of the crystals of this salt were gradually heated in a platinum crucible till

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the whole water and acid were driven off, and till the uranium was reduced to the state of protoxide. It now weighed 27 grains, which, from what has been already stated, is equivalent to 28 grains of peroxide.

(2.) 57·25 grains of the crystals of the same salt were dissolved in water, and the solution being mixed with about 30 grains of carbonate of barytes, was digested in a retort till it had become perfectly colourless: the whole was then thrown on a filter, which retained a yellow powder, consisting of the peroxide of uranium and the barytes, partly combined and partly mixed. The liquid being evaporated to dryness left 24·5 grains of nitrate of barytes, equivalent to 10·023 grains of nitric acid. This is less than 1½ atom of nitric acid by 0·1 grain, or almost exactly one per cent. The reason of this deficiency I found (after some trouble) to be owing to the filter employed containing some sulphate of lime, which decomposed a little of the nitrate of barytes; for I found distinct traces of lime in the filtered liquid, though neither the carbonate of barytes nor the salt of uranium contained a particle of that earth. It is evident, then, that 57·25 grains of the crystallized nitrate of uranium contain 10·125 grains of nitric acid, equivalent to 1½ atom of acid.

(3.) The remainder wanting to make up the original weight of the crystals, amounting to

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19·125 grains, must be the amount of the water of crystallization. It is equivalent to 17 atoms of water.

From the above analysis, which was very carefully conducted, it appears, that the salt is a sesquinitrate composed of

1½ atom nitric acid .	10·125
1 atom peroxide of uranium	28·000
17 atoms water . .	19·125
	57·25

7. When the pernitrate of uranium is exposed to heat, it gives out water and nitric acid, and loses the property of dissolving in water. In this state it is probably a neutral pernitrate; but my analysis of it was not successful.

Analysis of sesquisulphate of uranium.

8. Sesquisulphate of uranium. To form this salt I digested percarbonate of uranium in dilute sulphuric acid for more than a fortnight, till the acid would dissolve no more of the oxide. The yellow solution, thus formed, was evaporated to dryness by a gentle heat: the saline residue was redissolved in water, and the solution evaporated a second time to dryness in a temperature rather above 212°, and kept in that temperature till the yellow residue was reduced to the state of a yellow powder. No appearance of crystals could be perceived during the evaporation; but if a portion of sulphuric acid be added to the liquid,

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and we evaporate cautiously to dryness, the dry mass appears a congeries of small and ill-defined prisms.

The dry sulphate of uranium, thus formed, had a fine deep yellow colour and an astringent taste. It strongly reddened vegetable blues. This salt was analyzed in the following manner:

(1.) 36·8 grains of it were dissolved in distilled water: several yellow flocks remained undissolved—these being collected and dried were found to weigh 0·6 grain. Hence, the portion of the salt dissolved was 36·2 grains.

(2.) The aqueous solution was precipitated by ammonia. The yellow precipitate being collected on a filter, and washed with water containing a little ammonia, and then dried, was found to weigh 28·2 grains. This matter being exposed to a strong red heat in a platinum crucible, was reduced to protoxide of uranium, and weighed 24·434 grains; equivalent to 25·339 grains of peroxide of uranium.

(3.) The liquid, thus freed from uranium, was supersaturated by nitric acid and precipitated by muriate of barytes. The sulphate of barytes precipitated, being washed, dried, and heated to redness, weighed 23·67 grains, equivalent to 8·02 grains of sulphuric acid.

(4.) From the preceding experiments it follows that the constituents of the salt are

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Sulphuric acid	8·020
Peroxide of uranium	25·339
Water . .	3·746
	36·2

This is equivalent to

Sulphuric acid	8·862
Peroxide of uranium	28·000
Water . .	4·13

8·862 approaches nearest to 1½ atom of sulphuric acid which weigh 7·5; and 4·13 comes nearest to 4·5 which is 4 atoms of water. Hence, it is probable that the salt is a sesquisulphate of uranium mixed with a little bisulphate; and we may infer that the sesquisulphate of uranium, supposing it pure and dried till it falls to powder, is a compound of

1½ atom sulphuric acid	7·5
1 atom peroxide of uranium	28
4 atoms water	4·5
	40

I repeated this analysis several times with sulphate of uranium prepared in different ways, and exposed to as high a temperature as it could bear without acquiring a green tinge. Once I obtained a persesquisulphate of uranium, composed of

1½ atom sulphuric acid	7·5
1 atom peroxide of uranium	28
	35·5

But in general the sulphuric acid was an intermediate quantity between 7·5 and 8·8; I never came nearer 10 than in the analysis just given.

I conclude from these experiments, that sulphuric acid and peroxide of uranium are capable of uniting in two proportions, forming a bisulphate and a sesquisulphate; and that in general, both of these salts are mixed together.

Analysis of peroxalate of uranium.

9. Peroxalate of uranium. I dissolved 27 grains of the crystals of oxalic acid in water, and digested the solution over 127·5 grains of percarbonate of uranium, till the liquid refused to dissolve any more. The undissolved portion being separated, dried, and weighed, was found to amount to 83·7 grains. Hence, the portion dissolved weighed 43·8 grains.

Twenty-seven grains of crystallized oxalic acid contain 13·5 grains of oxalic acid, equivalent to 3 atoms of that acid. 127·5 grains of percarbonate of uranium contain 84 grains peroxide of uranium, likewise equivalent to 3 atoms. Now, 43·8 is very nearly the third of 127·5; hence, it is obvious, that the solution was a teroxalate of uranium, or a compound of

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3 atoms oxalic acid	13·5
1 atom peroxide of uranium	28
	41·5

The solution being evaporated let fall yellow crusts of the oxalate, which had little taste, and were scarcely soluble in cold water. But they dissolved in hot water; the solution had an astringent taste, and reddened vegetable blues.

Analysis of uraniate of potash.

10. Uraniate of potash. Arfwedson having shown that peroxide of uranium possesses the properties of an acid, I wished to see whether I could form a definite compound of this oxide and potash. For this purpose I digested on the sand bath a quantity of percarbonate of uranium in a pretty strong solution of caustic potash; the yellow colour of the powder was speedily changed into a deep orange, bordering on red, and its volume diminished. The caustic potash was poured off after two hours' digestion, and a fresh portion poured on, which was allowed to digest on the powder for twenty-four hours. The uraniate was then collected on a filter, washed, and dried in a low heat. I now examined it in the following manner.

(1.) Nineteen grains of it were dissolved in nitric acid in a balanced glass vessel. There was a slight effervescence, and the loss of weight amounted to 0·3 grain; this loss was occasioned by the escape of some carbonic acid gas.

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(2.) The nitric acid solution was evaporated to dryness, to get rid of the excess of acid—the dry mass re-dissolved in water, and precipitated by ammonia. The precipitate, which was orange, being collected on the filter, washed, and dried, weighed 16·5 grains. Being exposed to a red heat, it was reduced to protoxide of uranium, and weighed 14·04 grains; equivalent to 14·54 grains of peroxide of uranium.

(3.) The residual liquid was evaporated to dryness in a platinum cup, and exposed to a heat gradually raised nearly to redness. The nitrate of ammonia was decomposed and driven off, and there remained 2·7 grains of nitrate of potash, equivalent to 1·223 grain of potash.

(4.) Thus the constituents of the salt were

Peroxide of uranium	14·54
Potash . . .	1·223
Carbonic acid . .	0·300
Water . . .	2·937
	19·000

The carbonic acid was no doubt combined with a portion of the peroxide of uranium, showing that the carbonate had not been completely decomposed. If we subtract the portion of percarbonate, amounting to rather less than 6½ grains, we shall find that the uraniate of potash is a compound of

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2 atoms peroxide of uranium	56
1 atom potash . . .	6
3 atoms water . . .	3·375
	65·375

The preceding details contain the most satisfactory of the experiments which I made upon this very difficult metal. I consider them myself as proving that the atomic weight of uranium is 26; that its protoxide weighs 27, and contains 1 atom of oxygen; while its peroxide contains 2 atoms of oxygen and weighs 28. But some time after these experiments of mine had been concluded, I had an opportunity of seeing a paper on the Oxide of Uranium and its Compounds, by Professor Berzelius, which that excellent chemist has inserted in the Memoirs of the Stockholm Academy for 1823. Berzelius is of opinion that the oxygen in the protoxide of uranium is to that in the peroxides as 2 : 3. But I have not been able to perceive any thing in his experiments from which this inference can be legitimately drawn. He analyzed three salts of uranium; namely, potash sulphate of uranium, potash muriate of uranium, and oxalate of uranium. I shall here state the results of these analyses.

Experiments of Berzelius on the oxides of uranium.

(1.) The constituents of potash-sulphate of uranium he found as follows:

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Sulphuric acid .	26·834
Peroxide of uranium	53·833
Potash . .	15·833
Water . .	3·500
	100·000

The reader will be better able to form an estimate of the constituents of this salt if I state them in atomic proportions:

2½ atoms sulphuric acid	12·5	+	1·2
1 atom peroxide of uranium	28		
1 atom potash . .	6	+	2·308
1 atom water . .	1·125	+	0·699
	47·625		4·207

Or we may state the constituents this way:—

1 atom sulphate of potash .	11
1 atom sesquisulphate of uranium	35·5
1 atom water . . .	1·125
Excess of sulphuric acid .	1·2
——— potash .	2·308
——— water .	0·699
	51·832

The weight of the integrant particle of the salt is not much higher than I found it, but instead of the 4 atoms of water which I found, there is a surplus of potash and sulphuric acid, and not in such proportions that they saturate each other. It is quite obvious, that this salt as it was

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examined by Berzelius, was not a pure chemical compound of sulphate of uranium and sulphate of potash, but contained an excess of one of them mechanically mixed: this indeed Berzelius admits. Consequently, no inference can be drawn from the analysis just stated.

(2.) The potash-muriate of uranium was prepared by dissolving muriate of potash in an excess of permuriate of uranium, and allowing the salt to shoot spontaneously into crystals. The crystals were four-sided oblique prisms, or rhomboidal tables. The salt was previously dried in the temperature of 131°. From 1·5 gramme of this salt, he got 1·61 gramme of fused chloride of silver, equivalent to 0·408 muriatic acid. The protoxide of uranium was 0·82, equivalent to 0·85 peroxide of uranium, and the muriate of potash was 0·412 gramme, equivalent to 0·2602 potash. According to this analysis the constituents of the salt are

Muriatic acid .	0·4080	or	26·874
Peroxide of uranium	0·8500	-	55·987
Potash . .	0·2602	-	17·139
	1·5182		100·000

Though Berzelius himself, owing to some inadvertancy, has stated the constituents of this salt to be

Muriatic acid .	0·3075
Peroxide of uranium	0·8346
Potash . .	0·2606
Water . .	0·0973
	1·5000

I examined this salt with a good deal of care, and though, owing to an accident, I cannot state the result of my analysis, yet I satisfied myself that it exactly resembled the potash-sulphate of uranium in its constitution, that is to say, that it was a compound of 1 atom muriate of potash, and 1 atom of sesquimuriate of uranium, and without any sensible portion of water. Now, the preceding analysis of Berzelius comes exceedingly near mine, as will be evident from the following observations. The muriatic acid united to 0·2602 potash, must have been 0·20057; for

6 (the atom of potash) : 4·625 (the atom of muriatic acid) : : 0·2602 : 0·20057.

Consequently, there remains 0·20743 muriatic acid to saturate 0·85 peroxide of uranium. Now, if muriatic acid be to the oxide in the proportion of 1½ atom to 1 atom, an atom of peroxide of uranium will weigh 28·43; for

0·20743 : 0·85 : : 6·9375 (1½ atom muriatic acid) : 28·43.

I consider the analysis of Berzelius, therefore, to

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be a corroboration of my previous experiments. The slight excess 0·43 (little more than one per cent.) might be owing to the protoxide of uranium not having been absolutely free from foreign matter; and the slight excess of weight in Berzelius' numbers above the weight of the salt employed, rather confirms this view of the matter. I think it therefore certain, that the true constitution of potash-muriate of uranium is

1 atom sesquimuriate of uranium	34·9375
1 atom muriate of potash .	10·625
	45·5625

But the salt formed by Berzelius contained an excess of muriate of potash amounting nearly to a fourth part.

(3.) Peroxalate of uranium was also analyzed by Berzelius. He does not inform us of the method he employed to prepare it; but from the result of his analysis it is evident that it contained just twice as much peroxide of uranium as my oxalate did. A quantity of this salt previously well dried was subjected to distillation in a small retort. From 2·67 grammes of the salt he obtained 0·353 gramme water, 0·5835 gramme carbonic acid, and 1·7335 gramme uranium in the metallic state, equivalent to 1·8668 peroxide of uranium. Hence, the constituents of this salt must have been

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Peroxide of uranium	1·8668
Oxalic acid .	0·4502
Water . .	0·3530
	2·6700

Now, this is equivalent to

		RESULT OF EXPERIMENT.
1½ atom oxalic acid .	6·75	6·75
1 atom peroxide of uranium	28	27·925
2⅓ atoms water .	2·8125	2·8428
	37·5625	

Thus, the result of this analysis corresponds also exceedingly nearly with mine. The atom of peroxide from this salt falls short of 28 a very little; while the number from the muriate gave a result a little higher than 28.

(4.) Berzelius likewise formed uraniate of barytes by precipitating a solution of pernitrate of uranium with barytes water, and boiling the precipitate in water till all the soluble barytes was removed. 2·128 grammes of this uraniate previously heated to redness gave 0·451 of barytes, and 1·677 of peroxide of uranium. These determinations are merely given by Berzelius, without stating the weight of the sulphate of barytes and protoxide of uranium, from which they were derived. This puts it out of my power to apply any correction to them. According to this statement, uraniate of barytes is composed of

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Peroxide of uranium	1·677	or	36·254
Barytes . .	0·451	-	9·75
	2·128		

I suspect that the quantity of peroxide of uranium has been underrated in Berzelius' calculation, and that the uraniate of barytes, when pure, is a sesqui-uraniate composed of

1½ atom peroxide of uranium	42
1 atom barytes . .	9·75

Either this supposition is the true one, or the salt contained a slight excess of barytes, owing to the difficulty of washing it thoroughly: this last is the notion which Berzelius entertains. The composition of the salt may be stated thus:

1½ atom peroxide of uranium	42
1 atom barytes . .	9·75 + 1·546

If this statement be correct, there was an excess of 1·546 barytes, or almost ⅛th of the whole barytes.

(5.) Berzelius has likewise given us an analysis of uranmica from Autun, well known for its beautiful yellow colour. He found its constituents as follows: Analysis of uranmica.

Phosphoric acid .	14
Peroxide of uranium	56·813
Lime . . .	5·416
Water . .	14·250
	90·479

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Now, if we consider it as composed of

4 atoms phosphoric acid	14
2 atoms peroxide of uranium	56
1½ atom lime . .	5·25
12 atoms water . .	13·5
	88·75

we have almost the identical numbers of Berzelius. We may, therefore, represent the constitution of uranmica in this way:

2 atoms sesquiphosphate of uranium	66·5
1 atom subsesquiphosphate of lime	8·75
12 atoms water . . .	13·5
	88·75

The green uranmica, from Gunnis Lake mine, in Cornwall, had been shown, by Mr. Richard Phillips, to contain phosphoric acid. This induced Berzelius to analyze it, and the result of his experiments agrees very near with the numbers obtained by Phillips. He found its constituents:

Phosphoric acid .	14
Peroxide of uranium .	54·2
Oxide of copper .	7·59
Water . . .	13·54
	89 33

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Now, if we consider it as composed of

4 atoms phosphoric acid .	14
2 atoms peroxide of uranium	56
1½ atom oxide of copper	7·5
12 atoms water . .	13·5
	91

we have very nearly the numbers obtained by Berzelius. The greatest deviation is in the peroxide of uranium, which, instead of 56, turns out only 54·2. It is not impossible that it is in the state of protoxide of uranium, instead of peroxide. Meanwhile, it would seem that the difference between the yellow and the green uranmicas consists in this, that the former is a double sesquiphosphate of uranium and lime, and the second of uranium and copper; for the constitution of uranite from Cornwall may be represented thus:

2 atoms sesquiphosphate of uranium	66·5
1 atom subsesquiphosphate of copper	11
12 atoms water . . .	13·5
	91

As the two minerals have the same crystalline shape, and the same constitution nearly, it would appear that lime and oxide of copper are isomorphous bases.

Thus the experiments of Berzelius confirm my

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own in a very satisfactory manner; and seem to leave no doubt that the atomic weight of uranium and its oxides have been rightly determined.

The tendency which peroxide of uranium has to form sesquisalts is very curious. It would have led me to hesitate about the atomic weight of this metal, had I not likewise met with several neutral compounds of the peroxide of uranium and acids.

SECT. II.

OF THE ATOMIC WEIGHT OF ANTIMONY.

The laborious experiments of Proust and Berzelius to investigate the oxides of antimony are well known to the chemical world. It is unnecessary to refer to them farther than to say, that they guided me in my researches, and contributed essentially to the accuracy of my results.

Method of obtaining pure antimony.

To obtain pure antimony I dissolved the antimony of commerce in nitro-muriatic acid, and precipitated the peroxide by means of water. This oxide was well washed, dried, mixed with black flux, and exposed to a red heat in a covered crucible. The metallic antimony thus ob-

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tained was exceedingly soft, and its specific gravity was only 6·424, at the temperature of 60°. This is somewhat below the specific gravity of this metal usually given by chemists.

1. 5·5 grains of this antimony were put into a platinum crucible, and dissolved by the assistance of heat in nitric acid. The solution was evaporated to dryness, and exposed for some hours to a heat of 500°. A yellow coloured powder was thus obtained, possessing the properties of peroxide of antimony; it weighed 7·5 grains. Four different trials, made in the same way, gave each the same result. Thus it appears that peroxide of antimony is a compound of

Antimony . .	5·5
Oxygen . .	2
	7·5

It is evident that 5·5 is the atomic weight of antimony, and that peroxide of antimony is a compound of 1 atom metal and 2 atoms oxygen. Its atomic weight, therefore, is 7·5. Atom of antimony and peroxide.

2. 7·5 grains of peroxide of antimony were kept for some time in a red heat; the colour changed from yellow to white, and the weight diminished from 7·5 to 7. By this process the peroxide was changed into deutoxide; for the white powder possessed the well known proper- Atom of deutoxide.

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ties of deutoxide of antimony. The loss of weight sustained in this case was owing to the escape of oxygen; for, if 100 grains of peroxide of antimony be heated to redness in a small green glass retort, connected to a pneumatic trough, the gaseous product evolved, which is oxygen, amounts nearly to 19 cubic inches.

7·5 peroxide being converted into 7 deutoxide, it is plain that deutoxide of antimony is composed of

Antimony . .	5·5
Oxygen . .	1·5
	7

Or, it consists of 1 atom of antimony united to 1½ atom oxygen.

It is this deutoxide that is formed when any of the other oxides of antimony is exposed to a red heat. In this respect antimony and manganese resemble each other; for, whenever any oxide of manganese is exposed to a low red heat, it is always converted into deutoxide of manganese, which, like the deutoxide of antimony, is a compound of 1 atom manganese and 1½ atom oxygen.

Atom of protoxide.

3. It was unnecessary to subject the protoxide of antimony to any analysis; for, if we compare Berzelius' experiments on it with the analysis of the deutoxide and peroxide of antimony in

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the preceding paragraphs, it will be obvious that the protoxide must be a compound of

1 atom antimony .	5·5
1 atom oxygen .	1
	6·5

and its atomic weight must be 6·5.

Thus it appears, that the atom of antimony weighs 5·5; that the protoxide is a compound of 1 atom metal + 1 atom oxygen, and the peroxide of 1 atom metal + 2 atoms oxygen. The deutoxide may be considered as a compound of 1 integrant particle of protoxide and 1 integrant particle of peroxide. For

	ANTIMONY.		OXYGEN.
1 atom protoxide consists of	5·5	+	1
1 atom peroxide . .	5·5	+	2
	2)11	+	3
	5·5	+	1·5

or we may consider it as a compound of 2 atoms metal and 3 atoms oxygen.

Antimonite of potash.

The only chemical compound of this deutoxide, or antimonious acid as Berzelius calls it, hitherto examined, is antimonite of potash. Berzelius obtained this salt by fusing together deutoxide of antimony and potash, washing off the excess of potash by cold water, dissolving the

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residual matter in hot water, and evaporating the solution in order to obtain the antimonite which separated in the state of a white powder. According to the analysis of Berzelius, the constituents of the salt are

Deutoxide of antimony	76·6	or	19·641
Potash . . .	23·4	-	6
	100·0		

It is obvious that the salt contained an excess of deutoxide; had it been a binantimonite, it would have been composed of

2 atoms deutoxide of antimony	14	or	70
1 atom potash . . .	6	-	30
	20		100

Chlorides of antimony.

4. There are two chlorides of antimony, though only one of them has hitherto been described; both of them may be easily obtained by dissolving sulphuret of antimony in muriatic acid, and distilling the solution in a retort. There distils off a liquid having a straw yellow colour, containing both muriatic acid and antimony. The liquid in the retort, which was at first of rather a deep yellow, becomes gradually lighter, and at last quite colourless and transparent. When the concentration has been carried a certain length, the fire must be withdrawn, and the apparatus left untouched for twenty-four hours.

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A number of beautiful white scales, with a silky lustre, gradually make their appearance at the bottom of the liquid in the retort. These scales may be taken out and dried upon blotting paper: they do not deliquesce, and as far as I have observed, undergo no alteration whatever by exposure to the air. They may be dissolved, at least partially, in water without undergoing decomposition; by digesting them with a solution of carbonate of soda, I decomposed them; and by collecting the oxide of antimony, and determining the quantity of chlorine by means of nitrate of silver, I found that these scales constitute a dichloride of antimony composed of

1 atom chlorine	4·5
2 atoms antimony	11
	15·5

If the muriatic solution of antimony, thus deprived of the dichloride, be still farther concentrated, till liquid no longer passes into the receiver, the whole matter in the retort concretes on cooling into a solid mass, having a silky lustre, and the property of deliquescing very rapidly when exposed to the air. I have obtained it crystallized in octahedrons, usually having two of the opposite faces of the pyramids a good deal larger than the other two. Frequently, the octahedron does not terminate in a pointed summit, but forms a ridge; this is the substance

formerly called butter of antimony, and usually obtained by distilling a mixture of two parts corrosive sublimate and one part antimony. Its constituents are

1 atom chlorine	4·5
1 atom antimony	5·5
	10

as was shown long ago by Dr. John Davy.

Kermes mineral.

5. The dark red substance long celebrated under the name of *kermes mineral*, and constituting an excellent medicinal preparation, though but little used in this country, was suspected by Proust to be a compound of sulphuretted hydrogen gas and protoxide of antimony. Dr. John Davy demonstrated the truth of this opinion by showing that, when heated, it is converted into common sulphuret of antimony and water. When I published a similar set of experiments, about four years ago, I did not recollect at the time that I had been anticipated by Dr. Davy. It is obvious from the experiment just stated, that kermes mineral is a compound of 1 atom sulphuretted hydrogen and 1 atom protoxide of antimony. For sulphuretted hydrogen is a compound of

	ATOM.		ATOM.
	1 sulphur	+	1 hydrogen
Protoxide of antimony of	1 antimony	+	1 oxygen

The atom of sulphur combining with the atom

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of antimony forms an integrant particle of sulphuret of antimony; while the atom of hydrogen uniting with the atom of oxygen, forms an integrant particle of water.

Sulphuret of antimony.

6. That sulphuret of antimony is composed of one atom of each of its constituents, is obvious from the following experiment: 5·5 grains of pure antimony in powder were fused with a quantity of flowers of sulphur in a covered crucible, the temperature of which was gradually raised till the excess of sulphur was driven off. The weight of the sulphuret formed was 7·5 grains; consequently, the antimony had combined with 2 grains of sulphur. Now, 5·5 represents the weight of an atom of antimony, and 2 the weight of an atom of sulphur.

SECT. III.

OF THE ATOMIC WEIGHT OF CHROMIUM.

Oxides of chromium.

CHROMIUM is a white coloured brittle metal, which is not affected by the magnet, and which combines with three proportions of oxygen, and forms three oxides. The protoxide has a fine green colour, the deutoxide is brown, and the peroxide, commonly called *chromic acid*, has a very deep yellowish red, or extremely dark

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orange colour. It is very soluble in water, and possesses the characters of a strong acid.

Chromates. 1. The salts formed by the union of chromic acid and bases are called *chromates*. They have a *yellow* or a *red* colour; the chromates being commonly yellow, and the bichromates red. The bichromate of potash, being now used by the calico printers, is manufactured in Glasgow in very large quantities; it is a salt of a fine orange red colour, having a bitter and metallic taste, and is much less soluble in water than the chromate of potash.* It contains no water of crystallization, and as it bears a red heat without decomposition, it may be easily freed from all the water mechanically lodged between the plates of the crystals. It has been demonstrated, that in the bichromate of potash the quantity of acid is just twice as much as in the chromate. The bichromate reddens vegetable blues; but the chromate is neutral, and, consequently, a compound of one atom chromic acid and one atom potash. Of course, the bichromate is a compound of two atoms chromic acid and one atom potash. Either of these salts may be employed to determine the atomic weight of chromic acid; but the bichromate is much more easily procured in a state of purity, and therefore deserves the preference.

* For an account of the chromate and bichromate of potash, the reader is referred to the Annals of Philosophy, XVI. 321.

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2. Nineteen grains of anhydrous bichromate of potash were dissolved in distilled water, and in another portion of distilled water there was formed a solution of 41·5 grains of dry nitrate of lead. These two solutions being mixed together a double decomposition took place; chromate of lead was formed, and speedily fell to the bottom of the vessel, leaving a transparent colourless liquid which was not affected by sulphate of soda nor by nitrate of lead, and consequently, contained no sensible quantity either of lead or chromic acid. Thus it appears, that the oxide of lead in 41·5 grains of dry nitrate of lead just saturates the chromic acid in 19 grains of dry bichromate of potash; but the oxide of lead in 41·5 grains of nitrate is $14 \times 2 = 28$ grains, which is the equivalent for two atoms. Consequently, 19 grains of bichromate of potash contain a quantity of chromic acid just equivalent to 2 atoms.

Analysis of chromate and bichromate of potash.

If, instead of 19 grains of bichromate, we take 12·5 grains of anhydrous chromate of potash, and 20·75 grains of dry nitrate of lead, the result will be just the same; namely, the whole chromic acid of the chromate will be precipitated in combination with the whole oxide of lead in the nitrate. Consequently, 12·5 grains of dry chromate of potash contain just the equivalent of one atom of chromic acid.

The quantity of potash in 19 grains of bichro-

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mate and 12·5 grains of chromate of potash is just the same. The only difference between the two salts is, that the former contains two atoms of chromic acid while the latter contains only one. It is evident from this, that the difference between 19 and 12·5, which amounts to 6·5, must represent the weight of an atom of chromic acid.

Atom of chromic acid.

Chromate of potash is composed of

1 atom chromic acid	= 6·5
1 atom potash	= 6
	12·5

Bichromate of potash consists of

2 atoms chromic acid	= 13
1 atom potash	= 6
	19

3. Now, as there are three oxides of chromium, the probability is, that the atomic weight of chromium is 3·5, and that the three oxides are composed as follows:

	CHROMIUM.			OXYGEN.		ATOMIC WEIGHT.
Protoxide of	1	atom	+	1	atom	4·5
Deutoxide	1	atom	+	2	atoms	5·5
Chromic acid	1	atom	+	3	atoms	6·5

The protoxide combines readily with the different acids; but I have not been able to obtain any of the salts which it forms in the state

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of crystals, and consequently, susceptible of exact analysis. The muriate is a beautiful green solution, which may be evaporated to dryness without losing its colour. The sulphate is a dirty pale green powder, not soluble in water. Neither nitric, phosphoric, or acetic acids gave better results.

Atom of protoxide.

To determine the nature of protoxide of chromium I dissolved a quantity of chromate of potash in water, and added tartaric acid to the solution. An effervescence took place, and the solution assumed a fine green colour, because the chromic acid was converted into protoxide of chromium. Ammonia being poured into the green coloured liquid, the protoxide of chromium was precipitated. It was collected on a filter, well washed with water, and dried in the open air. In this state it constituted a fine green powder, exceedingly light, tasteless, and dissolving with facility in acids. I could detect no ammonia, nor tartaric acid, nor potash, in this powder; but found it a combination of water and protoxide of chromium. 33·75 grains of this hydrate were gradually heated to redness in a green glass retort. Water was driven off to the amount of 29·25 grains, and there remained a fine green powder, weighing 4·5 grains, and still in the state of protoxide of chromium; but it dissolves in acids with great difficulty, or not at all in several; because it is now anhy-

26 hydrate of protoxide.

drous. The reader will observe, that 29·25 represents 26 atoms of water. Hence, if protoxide of chromium weighs 4·5, the hydrate of it is a componnd of

1 atom protoxide of chromium	4.5
26 atoms water . . .	29·25
	33·75

This hydrate appears perfectly dry; yet it contains only $\frac{8}{15}$ths of its weight of solid matter, while $\frac{15}{15}$ths consist of pure water. I am not aware of any metallic hydrate that contains so great a proportion of water, or so many atoms of water as this one does.

Muriate of chromium.

337½ grains of this hydrate (containing 45 grains of protoxide of chromium) were dissolved in muriatic acid, and the solution cautiously evaporated in as low a temperature as possible till the muriatic solution was reduced to the state of a powder, apparently dry. It weighed 192·5 grains. From this experiment it is obvious, that the atomic weight of protoxide of chromium is 4·5; for the salt was neutral. Hence, every atom of the oxide must have combined with an atom of muriatic acid. The quantity being 45, equivalent to 10 atoms, must have united to 46·25 (equivalent to 10 atoms) of muriatic acid. The remaining 101·25, wanting to complete the sum, must be water, and it is equivalent to 90 atoms.

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Thus, we see that the constituents of this muriate are

1 atom muriatic acid .	4·625
1 atom protoxide of chromium	4·500
9 atoms water . .	10·125
	19·25

for this is just the weight of salt formed from 4·5 of protoxide of chromium.

Chloride of chromium.

These 192·5 grains of muriate of chromium were exposed in a close vessel to a heat raised very slowly nearly to redness. It had not undergone fusion, and was still a powder having an olive green colour. It weighed 82 grains. Had it been reduced to a pure anhydrous chloride of chromium, the weight would have been 80 grains; for it consisted (abstracting the water) of

Muriatic acid	46·25
Protoxide of chromium	45
	91·25

When converted into chloride it would lose 10 atoms of water, or 11·25. Now, 91·25 — 11·25 = 80. In the preceding experiment the muriate had not been completely, though very nearly, reduced to a chloride. When I subjected the muriate of chromium to a strong red heat, the loss of weight was always too great, owing to

the escape of chlorine; but these experiments, though not absolutely exact, are sufficient approximations to satisfy us that the atomic weight of chromium is 3·5, and that of the protoxide 4·5; and consequently, that it contains only 1 atom of oxygen combined with an atom of chromium.

Atom of chromium and protoxide.

Deutoxide, or chromous acid.

The brown oxide, as usually prepared, neither combines with acids nor bases: yet it may be made to combine with alkalies, and to form with them a soluble compound. This was ascertained in the following way:—on a quantity of chromate of soda in crystals I poured some alcohol, and digested the mixture: the yellow colour disappeared and the salt became green, owing to the conversion of the chromic acid into protoxide of chromium. This green matter was evaporated to dryness, and digested repeatedly in nitric acid —it assumed the colour of deutoxide of chromium. The whole was then evaporated to dryness to get rid of the nitric acid, and the residual brown matter was dissolved in water: I obtained a dark brown opaque liquid, which I concentrated as much as possible, and then set aside in order to obtain crystals; but none would form. The salt in this opaque liquid was obviously a combination of deutoxide of chromium and soda. It might, therefore, be called chromite of soda: probably the other chromites might be obtained by a similar process.

When a solution of chromate of potash is poured into a fresh solution of protosulphate of iron, there is deposited a dark brown powder, exceedingly similar, in its appearance, to the mineral usually distinguished by the name of *chromate of iron*. In this precipitate, the iron is in the state of peroxide; it immediately robs the chromic acid of a portion of its oxygen, and converts it into deutoxide. The mineral has not yet been analyzed with the requisite care; but from the analysis of Klaproth, it seems probable that it is composed of Bichromite of iron.

2 atoms deutoxide of chromium	9
1 atom peroxide of iron .	5
	14

I am disposed, therefore, to consider it as a bichromite of iron,—the chromate of iron, probably, does not exist.

Similar phenomena take place when chromate of potash is dropped into protosulphate of manganese. Probably the black precipitate, which I have not examined, is a chromite of manganese.

SECT. IV.

OF THE ATOMIC WEIGHT OF MOLYBDENUM.

Bucholz first showed that molybdenum combines with three proportions of oxygen. The

protoxide has a brown colour; the *deutoxide*, or *molybdous acid*, has a purple colour when anhydrous, but a beautiful indigo blue when mixed with water. The *peroxide*, or *molybdic acid*, is white, or when hot, yellow.

Atom of molybdenum and molybdic acid.

1. Bucholz found that 100 parts of molybdenum, when converted into molybdic acid, unite with 49 or 50 parts of oxygen. Now, if this acid be a compound of 1 atom metal + 3 atoms oxygen, (as is likely, from the existence of three oxides of molybdenum) it will follow, that the atomic weight of molybdenum is 6, and that of molybdic acid 9. For 50 : 100 : : 3 : 6.

Analysis of molybdate of potash.

To verify this estimate, I exposed a quantity of molybdate of potash to such a temperature as I knew, from previous trials, was sufficient to drive off all the water of crystallization. Fifteen grains of this anhydrous salt were dissolved in water, and mixed with a solution of 20·75 grains of anhydrous nitrate of lead: a double decomposition took place; and molybdate of lead precipitated in the state of a white powder. The supernatant liquid was colourless, and was neither affected by sulphate of soda nor by nitrate of lead; showing that it contained no sensible quantity either of lead or of molybdic acid.

We see from this experiment, that 15 grains of anhydrous molybdate of potash contain just the quantity of molybdic acid necessary to satu-

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rate the protoxide of lead in 20·75 grains of nitrate of lead. But 20·75 grains of nitrate of lead contains 14 grains of protoxide of lead, which is equivalent to an atom: 15 grains of anhydrous molybdate of potash, therefore, contains a quantity of molybdic acid equivalent to an atom. It must be in combination with an atom of potash. But as an atom of potash weighs 6, and the salt 15, it is plain that the weight of the atom of molybdic acid must be 9; and the anhydrous salt consists of

1 atom molybdic acid .	9
1 atom potash . .	6
	15

The molybdate of lead being collected and dried, weighed 23 grains. Now, it contained 14 grains of protoxide of lead; consequently, its constituents are

1 atom molybdic acid .	= 9
1 atom protoxide of lead	= 14
	23

2. Molybdate of potash crystallizes in small four-sided right prisms, terminated by rhombic bases. Its colour is white, with considerable lustre; it is opaque, and has a taste that puts one in mind of that of a weak solution of potash;

it renders cudbear paper violet, however carefully washed and crystallized. When exposed to the air it slowly deliquesces; this circumstance prevented me from being able to determine its water of crystallization. The salt dissolves readily in water, and the solution is transparent and colourless.

Action of reagents on

The characters of molybdic acid being rather imperfectly described in chemical books, I shall here state the effects of the different reagents upon a solution of this salt.

1. Prussiate of potash—Produces no change.
2. Gallic acid—Strikes a fine orange red, but occasions no precipitate.
3. Tincture of galls—Gives the same colour, and throws down a bulky orange red coagulum.
4. A piece of tin, with a drop of muriatic acid—Strikes a deep blue, and a dark blue precipitate falls.
5. Sulphuric acid—Throws down a chalk white precipitate, redissolved in an excess of acid. When this solution is evaporated nearly to dryness, it is colourless while hot; but on cooling, assumes a very beautiful blue colour, which continues, though the solution be diluted with water.
6. Nitric acid—A white precipitate, redissolved by an excess of acid. The solution being evaporated to dryness leaves a yellow crust, which becomes white on adding water.
7. Muriatic acid—The same. The solution being evaporated becomes green, and of a fine blue colour on adding water.
8. Phosphoric acid } —A white precipitate redissolved by
9. Arsenic acid } an excess of acid.

10. Chromic acid—A white flocky precipitate.
11. Acetic acid
12. Oxalic acid
13. Tartaric acid } —No effect.
14. Muriate of lime—O.
15. Muriate of magnesia—O.
16. Muriate of barytes—A copious white precipitate in powder.
17. Muriate of strontian—A copious white precipitate in small flocks.
18. Alum—Numerous white flocks.
19. Sulphate of glucina—Ditto.
20. Nitrate of zirconia—Milk white flocks.
21. Nitrate of lead—A copious white flocky precipitate.
22. Nitrate of silver—Abundance of white flocks.
23. Nitrate of mercury—Abundance of yellowish white flocks.
24. Protosulphate of iron—Abundance of reddish brown flocks.
25. Sulphate of copper—Abundance of greenish white flocks.
26. Sulphate of zinc—A copious white precipitate in powder.
27. Muriate of tin—A bulky dark buff precipitate in flocks.
28. Protomuriate of cerium—Numerous white flocks.
29. Sulphate of nickel—Milk white flocks.
30. Nitrate of cobalt—O.
31. Soda-muriate of rhodium—O.
32. Muriate of platinum—A yellow precipitate, having the appearance of triple muriate of platinum and potash.
33. Aqueous solution of oxide of osmium—O.
34. Protosulphate of manganese—A copious white flocky precipitate.

From the preceding table it is obvious, 1.

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That molybdic acid is disengaged from potash by sulphuric, nitric, muriatic, phosphoric, arsenic, and chromic acids; but not by acetic, oxalic, or tartaric acids. 2. That molybdates of potash, soda, ammonia, lime, magnesia, cobalt, and rhodium are soluble in water. 3. That the molybdates of all the other bases mentioned in the table are insoluble in water, or nearly so.

Atom of molybdous acid.

3. Bucholz formed molybdous acid by triturating in a mortar a mixture of 1 part metallic molybdenum and 2 parts molybdic acid, with a certain quantity of hot water, till the mixture assumed a deep blue colour. I find that it is easily formed by heating together a mixture of molybdic and muriatic acids, and continuing the heat till the whole muriatic acid is driven off. The molybdous acid formed in this way has a dark purple colour, but becomes of a fine indigo blue when water is poured on it. This acid effervesces with nitric acid, and is converted into molybdic acid. From Bucholz's process for obtaining this acid, it is obvious that it is a compound of 1 atom molybdenum and 2 atoms oxygen; consequently, its atomic weight must be 8.

Protoxide of molybdenum.

4. No accurate experiments have been made on the protoxide of molybdenum. My stock of molybdenum was too small to enable me to enter upon the investigation; but, since the atomic weight of molybdenum is known, and since it

has been shown that molybdous acid is a compound of 1 atom molybdenum and 2 atoms oxygen, and molybdic acid of 1 atom molybdenum and 3 atoms oxygen,—there is no reasonable ground of doubt that the protoxide is a compound of 1 atom molybdenum and 1 atom oxygen. Thus the atomic weight and composition of molybdenum and its oxides is

	MOLYBDEN.		OXYGEN.	ATOMIC WEIGHTS.
Molybdenum				6
Protoxide of	1 atom	+	1 atom	7
Molybdous acid	1 -	+	2 -	8
Molybdic acid	1 -	+	3 -	9

5. Sulphuret of molybdenum exists native, and is the mineral substance well known under the name of *molybdena*. It has a bluish colour, and the metallic lustre; is soft and sectile, and composed of thin leaves. It may be formed artificially, by heating together 1 part of molybdic acid and 5 parts of sulphur. Bucholz analyzed this sulphuret with sufficient accuracy, and showed that it was a compound of Sulphuret of molybdenum.

Molybdenum	3	or	6
Sulphur	2	-	4
	10		

It is, therefore, a bisulphuret, or a compound of 1 atom molybdenum, with 2 atoms sulphur.

SECT. V.

OF THE ATOMIC WEIGHT OF TUNGSTEN.

The only chemist who has hitherto attempted to determine the atomic weight of tungsten and its compounds is Berzelius.* He has shown that this metal combines with two proportions of oxygen, and forms two oxides. The *protoxide* has a flea brown colour, and, when heated, burns like tinder, and is converted into tungstic acid. The *peroxide*, or tungstic acid, has a *yellow* colour, when obtained from wolfram by the usual process. When strongly heated, it becomes *green*; and, if we prepare it by heating tungstate of ammonia in close vessels, its colour is *blue*. Berzelius has shown that tungstic acid, of all these three colours, is the same in its composition. He formed protoxide of tungsten by putting tungstic acid into a glass tube, heating it to redness, and passing a current of hydrogen gas through the red hot acid, till it ceased to produce any farther change.

Experiments of Berzelius on the atoms of tungsten and its oxides.

100 parts of this protoxide, when converted into tungstic acid, became 107 parts. From this experiment of Berzelius it is obvious that tungstic acid is a compound of

* Annals of Philosophy, III. 244.

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Protoxide of tungsten	100
Oxygen . .	7
	107

Berzelius endeavoured to determine the quantity of oxygen in tungstic acid by a very ingenious experiment, but rather of too complicated a nature to be capable of perfect accuracy. He formed a sulphuret of tungsten, by heating 1 part of tungstic acid and 3 parts of cinnabar in a Hessian crucible. The mixture was covered with charcoal powder; and the crucible, with a flat lid on it, was exposed for half an hour to the greatest heat which he could raise in a wind furnace. The sulphuret thus obtained was a greyish black powder, which, when rubbed against a polished surface, acquired the metallic lustre, and resembled sulphuret of copper, but was rather more blue.

100 parts of this sulphuret were digested in nitromuriatic acid, till the sulphur was acidified. The sulphuric acid was thrown down by muriate of barytes; and the sulphate of barytes formed weighed 182 parts, equivalent to 24·678 parts of sulphur. Hence the sulphuret of tungsten is a compound of

Tungsten .	75·322
Sulphur .	24·678
	100·000

100 parts of the same sulphuret of tungsten, heated in a platinum cup till it disengaged no more sulphurous acid, left a brown powder, weighing 93·5. This powder, being exposed to a strong heat, became dark green, without any alteration of its weight; hence Berzelius considered it as tungstic acid.

From this experiment it follows, that tungstic acid is composed of

Tungsten	75·322	or	80·558
Oxygen	18·178	-	19·442
	93·500		100·000

But 107 tungstic acid contains 100 protoxide of tungsten and 7 oxygen; or, its constituents may be stated thus:

Tungsten .	86·197
Oxygen .	20·803
	107·000

If from the 20·803 we subtract 7, there will remain 13·803 for the oxygen in 100 parts of protoxide of tungsten.

From this it appears, that the composition of the oxides of tungsten is as follows:

Protoxide	86·197	tungsten	+	13·808
Tungstic acid	86·197	-	+	20·803

But 13·803 : 20·803 : : 2 : 3 very nearly. Thus

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it appears, that the oxygen in the protoxide is to that in the peroxide as 2 to 3; so that, if the protoxide be a compound of 1 atom tungsten and 1 atom oxygen, the peroxide must be a compound of 1 atom tungsten and 1½ atom oxygen. Thus we see that the oxides of tungsten in this respect resemble the oxides of iron, nickel, cobalt, and cerium.

Tungstate of ammonia.

I shall now state the experiments which I made, in order to ascertain the atomic weight of tungstic acid.

1. I first prepared a considerable quantity of tungstate of ammonia from wolfram, by heating wolfram in powder alternately in muriatic acid and ammonia, till the mineral was decomposed. The ammoniacal solutions, when properly concentrated, deposited the tungstate of ammonia in small brilliant crystals.

Of this tungstate I obtained two different varieties. The first was crystallized in four-sided rectangular prisms with rhombic bases. When put into the mouth this salt appeared at first tasteless, but in a short time it left a bitter impression on the palate, which was succeeded by a certain degree of sweetness mixed with a disagreeable metallic taste. This salt was so very sparingly soluble in water, that the solution did not answer well for determining the effect of reagents upon tungstic acid salts.

But in some of my other processes, I got a

tungstate of ammonia which crystallized in silky plates. Its taste was much stronger, though similar, and it was much more soluble in water. I employed this last salt to determine the action of reagents on its solution. I shall state the results which I obtained, conceiving them calculated to throw considerable light on the affinities and compounds of tungstic acid.

Action of reagents on

1. Prussiate of potash—No effect at first; but after a little time a white precipitate falls.
2. Gallic acid
3. Tincture of galls } —O.
4. Sulphuric acid—A white precipitate in flocks.
5. Nitric acid—Ditto.
6. Muriatic acid—Ditto; soluble in an excess of acid.
7. Phosphoric acid—O.
8. Arsenic acid—O.
9. Acetic acid—O.
10. Oxalic acid—O.
11. Tartaric acid—O.
12. Chromic acid—O.
13. Muriate of barytes—A white precipitate in flocks.
14. Muriate of strontian—Ditto.
15. Muriate of lime
16. Nitrate of lime } — { A white precipitate, which disappears on agitation.
17. Muriate of magnesia—O.
18. Alum—A white precipitate in powder.
19. A fragment of tin with a drop of muriatic acid—White flocks first separate, which gradually acquire a blue tinge, and a deep blue colour surrounds the tin globule.
20. Protosulphate of iron—A yellowish white precipitate in powder.

21. Persulphate of iron with excess of acid—Ditto; redissolved on agitation.
22. Sulphate of nickel—O.
23. Nitrate of cobalt—A light pink precipitate.
24. Sulphate of manganese—A copious white precipitate in powder.
25. Sulphate of zinc—A white precipitate, redissolved by agitation.
26. Nitrate of lead—A white flocky precipitate.
27. Muriate of tin—A copious white flocky precipitate.
28. Sulphate of copper—A white precipitate in powder.
29. Nitrate of mercury—Copious milk white flocks.
30. Nitrate of silver—A copious white flocky precipitate.
31. Muriate of platinum—O.
32. Muriate of palladium—O.
33. Soda-muriate of rhodium—O.

From the preceding table it appears that sulphuric, nitric, and muriatic acids have a stronger affinity for ammonia than tungstic acid; but phosphoric, arsenic, chromic, and the vegetable acids are incapable of disengaging that acid from ammonia.

The tungstates of barytes, strontian, lime, alumina, iron, cobalt, manganese, zinc, lead, tin, mercury, copper, and silver are insoluble, or nearly so. But tungstates of magnesia, nickel, platinum, palladium, and rhodium are probably soluble in water.

After some attempts to analyze the tungstate of ammonia, I was induced to abandon that salt as not likely to yield satisfactory results, and to have recourse to tungstate of soda.

Analysis of tungstate of soda.

2. Tungstate of soda, formed by boiling together a solution of carbonate of soda and tungstic acid, till the liquid refused to take up any more of the acid, was set aside after being concentrated as far as possible, so as to retain the liquid state. In about a week it shot into fine crystals of tungstate of soda; these crystals were white and semitransparent. The first time I obtained them in pretty regular short six-sided prisms; but the second time I repeated the process, the salt shot into flat rhombic prisms. The lustre of these crystals is silky; however carefully washed, they give a violet colour to cudbear paper, and restore the blue colour of litmus paper reddened by acetic acid. Yet the solution, from which they had crystallized, had been boiled for nearly a fortnight with a considerable excess of hydrated tungstic acid. The taste of this salt is at first sweet, but it speedily becomes an intense and pure bitter, almost exactly similar to the taste of quassia.

3. After a considerable number of trials, which it is needless to detail, I found that when 29·5 grains of these crystals are dissolved in water, and mixed with a solution of 20·75 grains of dry nitrate of lead, a double decomposition takes place; tungstate of lead precipitates in a white powder, and the residual liquid is neither affected by sulphate of soda nor by nitrate of lead; showing, that it contains no sensible quantity

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either of oxide of lead or of tungstic acid. The tungstate of lead that had been precipitated, being collected, washed, dried, and exposed to a red heat, was found to weigh 32·75 grains; but it contained just the quantity of protoxide of lead in 20·75 grains of nitrate: which has been shown before to amount to 14 grains. Hence, it follows, that tungstate of lead is composed of

Tungstic acid	18·75
Protoxide of lead	14
	32·75

14 being the equivalent for an atom of protoxide of lead, and the salt being neutral, 18·75 must represent the atomic weight of tungstic acid. Atom of tungstic acid.

4. 29·5 grains of crystallized tungstate of soda being heated on the sand bath, gave out a quantity of water, and fell into a white powder. This white powder being heated to redness, melted, and formed a kind of enamel, which it was very difficult afterwards to separate from the inside of the platinum crucible, to which it had attached itself. The loss of weight amounted to 6·75 grains. Now, 6·75 is the equivalent for 6 atoms of water.

Thus, we learn that 29·5 grains of crystallized tungstate of soda contain 18·75 of tungstic acid, and 6·75 of water. The remaining 4 grains must be soda, and the constitution of the salt may be stated as follows:

1 atom tungstic acid .	18·75
1 atom soda . .	4
6 atoms water . .	6·75
	29·50

The salt, while on the sand bath, lost 5·86 grains of weight, so that the quantity which remained was less than an atom.

5. From Berzelius' experiments, related at the beginning of this section, there is reason to conclude, that tungstic acid contains 3 atoms of oxygen, and brown oxide of tungsten 2 atoms; consequently, the atomic weight of tungsten must be 15·75, and that of brown oxide 17·75.

Atom of tungsten and oxide of tungsten.

6. From my experiments on the tungstate of ammonia, compared with the analysis of it by Berzelius, I have little doubt that its constituents are

2 atoms tungstic acid .	37·5
1 atom ammonia	2·125
2 atoms water . .	2·25
	41·875

The quantity of the most soluble tungstate of ammonia in my possession was too small to admit of an accurate analysis, but it certainly contained a smaller proportion of acid than the least soluble tungstate. Probably, therefore, it is a compound of 1 atom acid and 1 atom ammo-

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nia; but this must be left for future investigation.

7. Berzelius precipitated nitrate of lead by means of bitungstate of ammonia, and obtained a tungstate of lead composed of

Tungstic acid . .	34·866
Protoxide of lead .	14
	48·866

It was obviously a bitungstate, and quite different from that which I obtained from tungstate of soda by means of nitrate of lead.

It is evident from this, that it would be hazardous to attempt the analysis of tungstates by means of nitrate of lead: the precipitate might be either a tungstate or bitungstate of lead; and most frequently it would be a mixture of both.

SECT. VI.

OF THE ATOMIC WEIGHT OF COLUMBIUM.

This metal was discovered in 1801, by Mr. Hatchett, in a black mineral in the British Museum, which had been sent by Dr. Winthorp to Sir Hans Sloane, from Massachussets in North America. Mr. Hatchett found the constituents of this mineral to be about

Columbic acid . .	77·5
Protoxide of iron . .	18·9*
	96·4

He gave the metal the name of columbium, from Columbia, the poetical name for America; because the ore which contained it came from that quarter of the world.

Discovery of tantalum.

About two years after Mr. Hatchett's paper was published, there appeared in the Memoirs of the Academy of Sciences at Stockholm, the analysis of two minerals by M. Ekeberg, to which that gentleman had given the names of *tantalite*, and *yttrotantalite*. The former of these minerals was from Finland, the latter from the quarry of Ytterby in Roslagen, Sweden. In both of these minerals Ekeberg discovered the oxide of a peculiar metal, to which he gave the name of *tantalum*, because it was nearly insoluble in the mineral acids. In 1809, Dr. Wollaston demonstrated that the columbium of Hatchett and the tantalum of Ekeberg were one and the same metal. Berzelius, alleging that the oxide examined by Hatchett was merely a mixture of columbic and tungstic acids, has thought proper to ascribe the discovery of this metal to Ekeberg, and on that account has adopted the name tantalum assigned it by Ekeberg.

* Mr. Hatchett obtained 21 grains of peroxide of iron. But we know from a subsequent analysis of Berzelius, that the iron in the ore is in the state of protoxide.

The evidence which Berzelius has advanced in support of this opinion is the statement by Hatchett, that when his powder was fused with phosphate of ammonia before the blow pipe in a platinum spoon, the globule, when cold, had a deep blue colour, with a tinge of purple. Now, it is well known that tungstic acid produces this effect when fused with phosphate of soda; whereas, columbic acid melts with that salt into a white transparent globule. Berzelius found tungstic acid in some specimens of *columbite*, which he examined, from the neighbourhood of Fahlun, and he was informed that Ekeberg had examined the columbic acid of Hatchett, and had found it a mixture of the oxides of columbium and tungsten.

With respect to Mr. Hatchett's experiment, it will be impossible to account for it, unless we suppose that some tungstate of potash, which he was obviously using, as appears from his paper, had accidentally got into the platinum spoon and produced the blue colour of the bead. That the specimen in the British Museum, examined by Mr. Hatchett, contained no tungsten is next to certain, because Dr. Wollaston did not find any in it; and though he made a trial on purpose at my request, when Professor Berzelius informed me of his opinion, he was still unsuccessful. I conceive, therefore, that it is but an act of justice to Mr. Hatchett to retain the name *columbium*, which he originally imposed.

Both Hatchett and Ekeberg had tried unsuccessfully to reduce the oxide of columbium to the metallic state. But Berzelius, Gahn, and Eggertz, were more successful in the year 1815; and Berzelius, in the fourth volume of the Afhandlingar, published a detailed account of the properties of this metal, and the result of a set of experiments to determine the proportion of oxygen with which it unites in order to be converted into the white oxide, to which Hatchett gave the name of columbic acid.

After these introductory remarks, I shall proceed to relate the experiments which I have made in order to determine the atomic weight of columbic acid.

Preparation of columbic acid.

1. 162 grains of oxide of columbium, which I had procured from the Finland mineral called tantalite, was fused in a platinum crucible with six times its weight of anhydrous carbonate of soda: water was poured upon the fused mass to soften it, and the crucible having been inadvertently left on the sand bath till the water was driven off, I found the whole matter converted into large, white, opaque prismatic crystals. The quantity of salt and oxide having been too great for the size of my crucible, I had been obliged to divide it into two portions. After the first portion had been washed out of the crucible, I repeated the fusion with the second portion: the fused mass was digested with water, and the

water driven off as at first. The result was precisely the same. I have been induced to give an account of the appearance of these crystals as a curious fact. I did not examine them, but dissolved the whole in water, expecting that it would be in my power to form them at pleasure; but none of my subsequent attempts to obtain similar crystals was crowned with success.

The aqueous solution of the fused mass contained all the alkali, and the greatest part of the oxide of columbium, but not the whole. To separate this undissolved portion, which amounted only to a few grains, the liquid was passed through the filter. The liquid was now decomposed by sulphuric acid, in order to obtain columbic acid in the state of a hydrate. This hydrate was collected on the filter, and, being well washed with water, was allowed to dry in the open air.

2. Hydrated columbic acid thus obtained was a white tasteless powder. When placed upon litmus paper, it gave it a lively red colour; and yet I could not detect in it the presence of any acid. This property had been observed by Hatchett, and induced him to consider the oxide as an acid. It was soluble in sulphuric and muriatic acids; but I could not succeed in saturating these acids with it, nor indeed in perceptibly diminishing their acid properties;—and though it dissolved in the vegetable acids, as Dr. Wol-

laston had discovered, no definite compound or crystallizable salt seemed to be formed. Neither could I succeed in saturating an alkali with it, by boiling it in an alkaline ley, although I continued the process for several weeks.

The alkaline ley employed was a weak solution of caustic soda. The solution was at length decanted off, and, being concentrated on the sand bath, was set aside for 24 hours. Next morning a number of crystals were deposited; they were white, had a most beautiful silky lustre, and the form of scales similar to boracic acid. Mr. Hatchett had formed similar crystals, with potash and columbic acid; but neither Dr. Wollaston nor Professor Berzelius obtained any crystallizable salt in their experiments.

I found, likewise, that I could obtain similar crystals, by concentrating the solution formed by digesting water on a mixture of 1 part columbic acid and 6 parts anhydrous carbonate of soda, fused in a platinum crucible.

Columbate of soda.

3. Columbate of soda, as these crystals may be called, had an alkaline taste, and rendered cudbear paper purple; but the salt contained no excess of soda: for neither the taste nor the power of acting on cudbear paper was altered by digesting the salt in alcohol. When water was poured on these crystals, they assumed at first the appearance of beautiful silky flocks, but gradually dissolved. It will be worth while to

state the effect of reagents upon rather a dilute solution of this salt in water. The reader may compare these effects with the corresponding experiments by Hatchett.*

Action of reagents on

1. Prussiate of potash—No change.
2. Gallic acid—The liquid assumed a fine orange, inclining to red, but no precipitate fell.
3. Tincture of nut galls—The same.
4. Sulphuric acid
5. Nitric acid
6. Muriatic acid
   —A milk white precipitate in flocks.
7. Phosphoric acid
8. Chromic acid
9. Acetic acid
   —Milk white flocks.
10. Arsenic acid—O.
11. Oxalic acid—O.
12. Tartaric acid—O.
13. Oxalate of Ammonia—O.
14. Tartrate of potash—O.
15. Nitrate of lead—A copious milk white precipitate in flocks, not redissolved by nitric acid.
16. Sulphate of copper—A milk white precipitate.
17. Nitrate of silver—A copious milk white precipitate.
18. Sulphate of zinc—A milk white precipitate.
19. Sulphate of manganese—The same.
20. Nitrate of mercury—The same.

Analysis of

4. My next object was to analyze this columbate of soda, in order to determine the atomic weight of columbic acid.

(1.) When 34·25 grains of these crystals were heated on the sand bath, they lost their silky

* Phil. Trans. for 1802.

lustre, and assumed the appearance of an opaque white matter like chalk; but at this temperature the whole water of crystallization was not driven off; the salt was, therefore, exposed to a red heat. The loss of weight was 11·25 grains. Now, 11·25 is equivalent to 10 atoms of water.

(2.) The salt, thus rendered anhydrous, was digested for a long time in water acidulated with muriatic acid. The whole was then thrown on a filter; and the columbic acid, after being well washed, dried, and heated to redness, weighed 19 grains.

(3.) The muriatic liquid was saturated with carbonate of ammonia, gradually evaporated to dryness in a platinum crucible, and the dry mass which remained exposed to a heat sufficient to expel the sal-ammoniac which constituted the principal part of it. There remained a quantity of common salt, which weighed almost exactly 7·5 grains. This is equivalent to 4 grains of soda.

From this analysis it appears, that the crystals of columbate of soda are composed as follows:

Columbic acid .	19
Soda . .	4
Water . .	11·25
	34·25

4 is equivalent to an atom of soda, and 11·25 to 10 atoms of water. As the salt renders cudbear

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paper purple, it is clear that it can contain only 1 atom of columbic acid at the very utmost; consequently, 19 must represent the atomic weight of columbic acid. Atom of columbic acid.

5. I found the hydrate of columbic acid formed, by drying the precipitated acid in the open air, a compound of Hydrate of columbic acid.

1 atom columbic acid	.	19
7 atoms water	. .	7·875
		26·875

Berzelius seems to have obtained a hydrate, containing a much smaller proportion of water. Probably it had been dried in a much higher temperature than mine.

6. Berzelius could form only one oxide of columbium, namely, columbic acid. He informs us, that, when 100 parts of columbic acid were reduced to the metallic state, the metallic tantulum formed weighed 94·8. Now, if the quantity of metal had been 94·737, instead of 94·8, it would have exactly corresponded with the atomic weight of columbic acid as above determined; for, Berzelius' experiments on the metal.

5·263 (the oxygen in the acid) : 94·737 (the quantity of base in it) : : 1 : 18.

Thus it appears, that Berzelius' analysis of the

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columbic acid, and my determination of its atomic weight, correspond exceedingly well.

There is no reason, therefore, to doubt that the atomic weight of columbium is 18; and that columbic acid is a compound of 1 atom columbium and 1 atom oxygen.

SECT. VII.

OF THE ATOMIC WEIGHT OF TITANIUM.

Discovery of metallic titanium.

TITANIUM, in the metallic state, was discovered by Dr. Wollaston, in 1822, in the slag at the bottom of the iron smelting furnace at Merthyr Tydvil, in South Wales; and he determined and described its properties with his usual sagacity and precision.* It has the form of small smooth cubes, having a red colour, exceedingly similar to that of copper. The cubes are hard enough to scratch rock crystal, and cannot be fused by the highest temperature which can be raised by the blow pipe. Its specific gravity, as determined by Dr. Wollaston, is 5·3. It is brittle—conducts electricity. From the situation in which it occurs, we may infer that it does not combine with iron, and Dr. Wollaston tried in vain to unite it with lead, tin, silver, and copper.

* Phil. Trans. 1823, p. 17.

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These cubes of metallic titanium are not absolutely free from iron. They are not sensibly attracted by the magnet; but Dr. Wollaston found that, when suspended by a fine thread, a magnet drew it about 20 degrees from the perpendicular. He succeeded in detecting the presence of iron in it, and calculated the amount of that metal at $\frac{1}{250}$th part of the weight of the titanium.* From an experiment which I shall state below I am disposed to conclude, that the proportions of iron present in these cubes of titanium is still greater than this.

When metallic titanium is heated in the open air its surface is oxydized, assuming a blue or rather purple colour. The process goes on better in melted nitre, and if we add some borax to dissolve the oxide as it forms, the oxydation is still farther accelerated. I found also, that when metallic titanium in powder was fused in a platinum crucible with carbonate of soda, it was converted into protoxide.

Oxides of titanium.

1. Titanium appears capable of combining with two doses of oxygen, and of forming two oxides. The protoxide is *blue*, and has been found native in slender elongated octahedrons, which have been distinguished by the name of *anatase*. It has a specific gravity of 3·857, according to Hauy. The peroxide, when pure, is

* Phil. Trans. 1823. p. 200.

snow white. It possesses the properties of a weak acid, and has in consequence been called *titanic acid* by M. H. Rose, to whom we owe by far the best set of experiments hitherto made on it.* Titanic acid occurs native in the form of long prisms, or needles having usually a reddish colour, and therefore called *red schorl.* It is never quite pure, being always combined with peroxide of iron; though hitherto no good method has been discovered of separating peroxide of iron from titanic acid, and determining the quantity of each. Titanic acid occurs, likewise, united to a considerable proportion of peroxide of iron in black grains like gunpowder, and distinguished by the names of menaccanite, nigrine, and iserine, according to the size of the grains.

2. M. H. Rose is the first chemist who obtained titanic acid in a state of purity. It will be proper, therefore, to state his mode of proceeding before attempting to investigate the atomic weight of this substance. He employed *rutile* or red schorl for this purpose. The mineral was reduced to a fine powder, and fused with thrice its weight of carbonate of potash. The mass was softened with water, and the compound of titanic acid, peroxide of iron, and potash was dissolved in muriatic acid, and mixed

* Kong. Vetensk. Acad. Hand. 1821. p. 231.

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with an excess of ammonia. Flocks fell down, which consisted of titanic acid and peroxide of iron, still in combination with each other. These flocks were washed, and put into a flask while still moist, and hydrosulphuret of ammonia poured over them. In this situation the mixture was left for some time. The iron was gradually converted into a sulphuret, while the titanium still continued in the state of titanic acid. The hydrosulphuret of ammonia being washed off, and the residuum digested in muriatic acid, the iron was dissolved, and the titanic acid left behind in a state of purity.

Properties of titanic acid.

Titanic acid, thus obtained, has a fine white colour. When heated to redness it becomes yellow, but when cold the original white colour again appears. After exposure to a red heat, it is insoluble in acids; but when precipitated from muriatic acid by heat it continues slightly soluble in that acid. When precipitated titanic acid is digested in water, that liquid passes milky through the thickest paper, and the acid cannot be collected on the filter; but this property is destroyed by an acid, or an alkali, or even a neutral salt. When titanic acid is fused with potash, and dissolved in muriatic acid, and the solution evaporated, the titanic acid often gelatinizes, but the jelly is never so stiff as that of silica. When titanic acid, precipitated by heat, is dried by a gentle heat, the surface is

covered by a brownish shining crust. This crust becomes white when heated to redness, but still appears as if the whole were coated with varnish. When titanic acid is precipitated by ammonia, and the dried bulky precipitate is heated to redness, we obtain a mass cohering together, having a brownish colour, an adamantine lustre, and a good deal of resemblance to the native oxide of titanium, called *rutile*. When titanic acid heated to redness is laid upon litmus paper and moistened with water, the liquid becomes red, but the paper retains its blue colour. Titanic acid forms insoluble compounds with the alkalies; it combines with some acids, but does not neutralize them. As an acid, it is nearly as feeble as silica; hence the difficulty of determining its atomic weight. Such are the properties of titanic acid determined by M. Rose.

3. I shall now state the experiments which have been made to determine the atomic weight of titanic acid.

Bisulphuret of titanium

(1.) Rose prepared a sulphuret of titanium in the following way: Titanic acid was made into a paste with water, dried, and heated to redness. By this contrivance it formed a cohering mass, which was put into a porcelain tube; a small retort, containing bisulphuret of carbon, was luted to one extremity of this tube, and a glass tube to the other extremity. The porcelain tube was heated to redness, and then the bisulphuret

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passed very slowly through it. The heat of the furnace was found sufficient to produce this effect, though the retort was at some distance from it; the process lasted six hours. When it was terminated, the glass tube was sealed hermetically, that the sulphuret of titanium might cool, while surrounded with the vapour of bisulphuret of carbon.

Sulphuret of titanium thus formed has a dark green colour. When rubbed against a hard body, it assumes the metallic lustre:—the streak is brass yellow. When heated in an open vessel, it burns with a blue flame, giving out the fumes of sulphur, and leaves titanic acid. When heated with nitric acid, nitrous gas is given out, and titanic acid is formed, while sulphur separates.

Analyzed. 1·017 gramme of sulphuret of titanium, when burned on a platinum plate, left 0·757 of titanic acid. Hence, 1·000 would have left 0·7443 titanic acid.

0·19 of sulphuret of titanium, were digested for eight days in nitro-muriatic acid, till the sulphur was acidified. The titanic acid was then precipitated by ammonia, and the sulphuric acid by means of muriate of barytes. The sulphate of barytes obtained weighed 0·679. Hence, 1·000 sulphuret of titanium would have given 3·5737 of sulphate of barytes, equivalent to 0·48457 sulphur.

If we subtract the 0·48457 sulphur from 1·000,

the original weight of the sulphuret of titanium, we obtain 0·51543 for the titanium in the compound. Hence, its constituents must be

Titanium	51·543	or	4·2547
Sulphur	48·457	-	4
	100·000		

4 representing the weight of two atoms of sulphur, it follows from this experiment that the compound is a bisulphuret, and that an atom of titanium weighs 4·2547.

But the titanic acid from 1·000 of sulphuret of titanium was 0·7443; which, as appears from the preceding calculations, contained 0·51543 of titanium. Hence, titanic acid must be a compound of

Titanium	0·5154	or	4·5035
Oxygen	0·2289	-	2
	0·7443		

2 representing the weight of two atoms of oxygen, 4·5035 must represent the weight of an atom of titanium.

Thus, from the analysis of bisulphuret of titanium by Rose, we have obtained two different atomic weights of titanium, namely 4·25 and 4·5. I am disposed to consider the weight derived from the sulphur found by experiment, to be nearest the truth, as it is not absolutely certain that the whole titanium was converted into

titanic acid by the combustion. A little of it may have continued in the metallic state, or have been only converted into protoxide of titanium.

This experiment certainly gives us a near approximation to the atomic weight of titanium, though the want of exact agreement between the parts of it shows us that it is not quite accurate.

Acidification of titanium.

(2.) It occurred to me that I might probably come tolerably near the truth by acidifying metallic titanium by means of a mixture of potash and nitre, and determining the increase of weight. I took a quantity of metallic titanium, which I had procured from the slag of the furnace at Merthyr Tydvil, and mixing it with potash and nitre, exposed it to a red heat in a platinum crucible. The titanium was acidified, but the nitre and potash had acted on the crucible, blackened its interior surface, and oxydized 11 grains of the platinum which were mixed with the titanic acid. I attempted to separate this oxide of platinum from the titanic acid; but the result was not quite satisfactory. I therefore repeated the experiment in a small green glass retort. 4 grains of metallic titanium, 37·05 grains of nitre, and 5·88 grains of caustic potash, were mixed together, and kept for half an hour in a dull red heat in a green glass retort, the weight of which had been previously determined.

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The whole was then washed out of the glass with distilled water, and dissolved in muriatic acid, leaving 2·63 grains of metallic titanium behind; so that 1·37 grain of the titanium had been converted into titanic acid. This titanic acid was obtained partly by boiling the muriatic solution, and partly by mixing the residual liquid with ammonia, evaporating to dryness, and redissolving. The whole titanic acid, after being heated to redness, weighed 2·185 grains; it was white, but had a shade of brown, indicating the presence of peroxide of iron, which however I did not succeed in separating by means of muriatic acid. The retort, in which the titanium had been heated, had lost 0·1 grain of its weight; deducting this for silica, the true weight of the titanic acid was 2·085. And as the weight of the titanium from which it had been formed was 1·37, it is evident that titanic acid is a compound of

Titanium	1·37	or	3·8322
Oxygen	0·715	-	2
	2·085		

The result of this experiment gives us 3·8322 for the atomic weight of titanium. Though it was repeated again, the result did not differ materially from what has been stated. It is extremely difficult to obtain titanic acid perfectly free from all traces of potash when prepared in

the way just stated. Hence, its weight may have exceeded the truth a little; had the potash in it amounted to 0·035 grain, the atomic weight of titanium would have come out exactly 4. I am disposed to consider the mean of the weight derived from the sulphuret, and from the acid obtained from metallic titanium, as coming very near the truth. Now, this mean is 4·0434; which comes so near 4, that we may without hesitation pitch upon that number as the true atomic weight of titanium. The atomic weight of titanic acid is 6, and that of protoxide of titanium undoubtedly 5.

Ratio between the atoms of carbonic acid and titanic acid.

(3.) M. H. Rose employed another method to determine the saturating power of titanic acid. He mixed determinate weights of it with anhydrous carbonate of soda, and exposing the mixture to a red heat, ascertained how much carbonic acid gas was driven off precisely in the way described in a preceding part of this work, when I tried by a similar process to determine the atomic weight of silica. The following table exhibits the results of Rose's experiments.

Experiments.	Titanic acid used. GRAMMES.	Carbonate of Soda used.	Carbonic acid expelled.	Atomic weight of titanic acid.
1	0·544	2·595	0·252	5·913
2	0·624	3·684	0·318	5·396
3	9·469	2·453	0·234	5·512
4	0 3055	4·255	0·1475	5·696
5	0·498	4·112	0·2300	5·954

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It is obvious that the titanic acid occupied the place of the carbonic acid expelled; hence, if we suppose that the whole titanic acid combined with the soda, we can easily from these experiments determine the atomic weight of titanic acid. For as the carbonic acid expelled is to the titanic acid employed, so is 2·75 (the atom of carbonic acid) to the atom of titanic acid. In this way, the numbers in the last column of this table were calculated. The results obtained from these experiments, do not agree with each other. The smallest atomic weight of the acid derived from them is 5·396, and the greatest 5·954. It is obvious that in experiments of this nature, where we have no certain criterion to determine whether the whole titanic acid has combined with the soda, the highest result must come nearest the truth. Consequently, 5·954 is the most accurate atomic weight of titanic acid derived from these experiments. Now, this number differs less than one per cent. from 6, the atomic weight of this acid, which I consider as the most probable deduction from other experiments: it is therefore a confirmation of that deduction, and, together with my own experiment, shows that the atomic weight of this acid cannot be so high as 6·25.

Analysis of tert. titanate of soda.

(4.) M. Rose formed combinations of titanic acid with the two fixed alkalies, potash and soda. His method was, to fuse a determinate weight of

titanic acid with carbonate of soda or carbonate of potash; to dissolve the fused mass in water, and pass the whole through a filter. The compound of titanic acid and the alkali remained on the filter; it was washed and dried in the open air. Being heated to redness to drive off the water, the loss of weight was noted, and the excess of the weight of the anhydrous salt above that of the titanic acid was considered as the alkali.

The mean of two experiments conducted in this way gives the constituents of titaniate of soda as follows:

Titanic acid	75·10	or	19·737
Soda .	15·22	-	4
Water .	9·68	-	2·544
	100·00		

It would seem from this to be a compound of 3 atoms titanic acid, 1 atom soda, and 2 atoms water. If we consider the atomic weight of titanic acid to be 6, then the true constitution of the salt will be

3 atoms titanic acid .	18
1 atom soda . .	4
2 atoms water . .	2·25
	24·25

But the atomic weight of titanic acid will be (if

we suppose the experiments of Rose perfectly exact) $\frac{19{\cdot}737}{3} = 6{\cdot}579$, a quantity which certainly exceeds the truth somewhat.

Of quinte titaniate of potash.

The constituents of titaniate of potash, determined in the same way, from a mean of two experiments, are

Titanic acid	82·33	or	27·955
Potash .	17·67	-	6
	100·00		

Hence it would seem to be a compound of 5 atoms of titanic acid and 1 atom of potash. Now, $\frac{27{\cdot}955}{5} = 5{\cdot}591$, which constitutes the weight of an atom of titanic acid, according to these experiments. Thus we have two atomic weights of titanic acid:

1. From titaniate of soda	6·579
2. —— ——— potash	5·591
	2) 12·170
Mean . . .	6·085

a number which does not exceed 6 by much more than 1 per cent.

Combination of titanic acid and sulphuric acid,

(5.) Rose found that titanic acid is likewise capable of combining with acids. Let us see what deductions can be drawn from these compounds.

Titaniate of potash was dissolved in muriatic

acid, and sulphuric acid poured into the solution. A combination of titanic acid and sulphuric acid precipitated. It was washed, dried, dissolved in muriatic acid, and analyzed by throwing down the titanic acid by ammonia, and the sulphuric acid by muriate of barytes. The constituents were

Sulphuric acid	7·78	or	5
Titanic acid	76·83	-	49·377
Water .	15·39	-	9·890
	100·00		

It was probably a compound of

1 atom sulphuric acid .	5
8 atoms titanic acid .	48
9 atoms water . .	10·125
	63·125

If we take Rose's analysis as perfectly exact, then the atomic weight of titanic acid will be $\frac{49·377}{8} = 6·172$.

By a similar process he obtained a combination of titanic acid and oxalic acid, a white compound, composed (from a mean of two analyses) of

and oxalic acid.

Oxalic acid	10·405	or	4·5
Titanic acid	74·095	-	32·045
Water .	15·500	-	6·703
	100·000		

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It is probably a compound of

1 atom oxalic acid	.	4·5
5 atoms titanic acid	.	30
6 atoms water	. .	6·75
		41·25

If we calculate from Rose's analysis, the atomic weight of titanic acid will be $\frac{32{\cdot}045}{5} = 6{\cdot}409$.

Different atomic weights of titanic acid.

Thus no fewer than eight values have been obtained for the atomic weight of titanic acid.

1. From the analysis of the sulphuret .	6·250
2. From titanic acid from a given weight of sulphuret	6·500
3. From the acidification of titanium . .	5·832
4. From the decomposition of carbonate of soda	5·954
5. From the titaniate of soda . . .	6·579
6. From titaniate of potash . . .	5·591
7. From the compound of titanic and sulphuric acids	6·171
8. From ditto of titanic and oxalic acids .	6·409

The mean of all these values gives us 6·161 for the atomic weight; and if we were to reject the second value, which seems least likely to be correct, the weight would be 6·112. Now, from the law which has been so amply confirmed in the preceding chapters of this work, it follows, that the true weight must be either 6 or 6·25; and, as 6·112 is nearest the former of these numbers, 6, in all probability, is the true atomic weight of titanic acid.

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4. But it was the composition of menaccanite which induced me to fix upon 6 as the true atomic weight of titanic acid. We have four different analyses of menaccanite by Gregor, Klaproth, Lampadius, and Chenevix; but, as the ore, in the state in which it occurred in the valley of Menaccan, is a mixture of menaccanite and small grains of octahedral iron ore, and as none of these gentlemen seems to have taken the trouble to separate the true menaccanite from the iron ore, no dependence can be put upon the results which they obtained. The specimen of menaccanite analyzed in my laboratory had been given me by Mr. Gregor himself, to whom we owe the first knowledge of the substance. He had collected it himself; and he assured me that it was a portion of the very quantity which he had himself subjected to analysis. The largest particles of the ore were picked out, and great care was taken to reject every particle which was in the slightest degree obedient to the magnet. Analysis of menaccanite.

The ore was reduced to a very fine powder, and was digested in a platinum matrass, with muriatic acid, till all action was at an end. The titanic acid remained, and was collected on a filter, and washed with water acidulated with muriatic acid. It was then dried, ignited, and weighed.

The filtered liquid had a greenish yellow co-

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lour. When heated with nitric acid it became brown, showing the evolution of nitrous gas, and at last, when the gas had escaped, it became yellow. The peroxide of iron was precipitated with ammonia, ignited, and weighed. Its colour indicating the presence of manganese, it was dissolved in muriatic acid (with the exception of a few flocks of titanic acid), evaporated to dryness, and redissolved in water acidulated by muriatic acid. The peroxide of iron was precipitated by benzoate of soda. The filtered liquid was mixed with carbonate of soda, and boiled for some time: a brownish precipitate fell, which possessed the characters of oxide of manganese. There could be no doubt from the appearances that both the iron and manganese exist in menaccanite in the state of protoxide. The result of the analysis was as follows:

Titanic acid .	57·682	or	6·134
Protoxide of iron	40·108	-	4·5
Protoxide of manganese	2·210		
	100·000		

The two protoxides, having the same atomic weight, may be included together. By this analysis, the atomic weight of titanic acid was 6·134. Now, it was certain that it had not been quite freed from iron; for its colour was grey, and not snow white. And Rose has shown that titanic

acid cannot be completely freed from iron by acids. Now, 6·134 is very near 6·164, the weight deduced from a mean of all the other experiments related in this section; but we are certain that 6·134 is a little too high. Consequently, the true atomic weight of titanic acid must be 6, and not 6·25, or any intermediate number. True atomic weight of titanic acid.

It is obvious that menaccanite is a simple titaniate of iron, or a compound of 1 atom titanic acid and 1 atom protoxide of iron. Hence the true constitution of the ore is

1 atom titanic acid	6·0	or	57·143
1 atom protoxide of iron	4·5	-	42·857
	10·5		100

If any confidence can be put in the analysis of Klaproth, nigrine is a compound of 4 atoms titanic acid and 1 atom protoxide of iron; or, numerically, Nigrine.

4 atoms titanic acid	24
1 atom protoxide of iron	4·5
	28·5

I do not notice the manganese, because its atomic weight agrees with that of iron.

Iserine is probably identical in its composition with menaccane;—but no analysis of it hitherto made can be depended on; for it is much mix- Iserine.

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ed with foreign bodies, and, on account of the small size of the grains, these cannot be separated completely from the true iserine.

Sphene. The only remaining known ore of titanium (except the oxides) is *sphene*, which Rose has recently analyzed anew, and found to consist of an integrant particle of trisilicate of lime, united to an integrant particle of trititaniate of lime. Hence it consists of

1 atom trisilicate of lime	9·5
1 atom trititaniate of lime	21·5
	31

Or, its constituents may be stated in this way:

3 atoms silica	6	or	19·355
3 atoms titanic acid	18	-	58·064
2 atoms lime .	7	-	22·581
	31		100

This differs very considerably from the analysis of Klaproth; but that chemist was not in possession of a good method of separating titanic acid from silica.

CHAP. XIV.

OF THE ATOMIC WEIGHTS OF THE COMBUSTIBLE ACIDS.

The acids formed in organized vegetable bodies, or by the action of nitric acid on organized bodies, contain (with a very few exceptions) both carbon and hydrogen, united to oxygen in various proportions. When these acids are combined with a base, and distilled in a retort, they all give out combustible gases; most of them form oils, and several of them leave behind them a quantity of charcoal. All of them, therefore, when decomposed by heat, resolve themselves partly into combustible products, while this is not the case with any of the acids composed of a single base united to oxygen, or chlorine, or iodine. This difference has induced me to distinguish the acids with compound bases by the name of *combustible acids*.

About thirty combustible acids have been described by chemists, and distinguished by particular names; but by far the greater number of these bodies are of rare occurrence, and consequently, in a theoretical point of view, of very inferior importance. There are six of them

which are very much employed in chemical analyses, and with which, therefore, every chemist ought to be familiarly acquainted; and there are some others which, though scarcely ever employed in chemical investigations, yet have acquired considerable importance in consequence of their connection with the physiology of vegetables, or animals. I shall, therefore, in this chapter treat of the atomic weights of nine different combustible acids.

SECT. I.

OF THE ATOMIC WEIGHT OF OXALIC ACID.

This is, upon the whole, the most important of all the combustible acids as far as chemical analysis is concerned. It is usually crystallized, and the apparent figure is a flat four-sided prism terminated by a bihedral summit; but Mr. Brooke informs us that the primary form is an oblique rhombic prism. The rhombic base, to the unexperienced eye, passes for one of the sides of the flat prism; and as the crystal is usually attached by one of its sides, two of the lateral faces appear to the eye as the dihedral summit. Two of the opposite lateral edges are usually deeply truncated, which makes the prism six-sided instead of four-sided.* These crystals

Crystalline shape of oxalic acid.

* Annals of Philosophy, (second series) VI. 119.

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being always in the same state, it is of importance to know with precision the weight of them capable of neutralizing an atom of each of the bases. The following experiments were made to determine this point.

Composition of the crystals.

1. Nine grains of crystals of oxalic acid were dissolved in distilled water, neutralized by ammonia, and evaporated to dryness by a very gentle heat, in order to get rid of all excess of ammonia. The oxalate of ammonia, thus formed, was redissolved in water.

6·25 grains of pure calcareous spar were dissolved in very dilute muriatic acid; the solution was slowly evaporated to dryness, twice successively, in order to drive off any excess of acid which might have been present; and the muriate of lime, thus rendered neutral, was redissolved in water.

These two solutions being mixed together, a double decomposition took place, and the insoluble oxalate of lime gradually precipitated to the bottom, leaving a clear and transparent liquor, containing in solution the muriate of ammonia formed by the mutual decomposition of the two salts. This liquid, being tested by oxalate of ammonia and by muriate of lime, was not affected by either of these reagents, showing that it contained no sensible quantity either of lime or of oxalic acid.—From this experiment it

is evident, that the oxalic acid in 9 grains of the crystals just saturates all the lime in 6·25 grains of calcareous spar; but it has been already shown that the quantity of lime in 6·25 grains of the carbonate is 3·5 grains, which is equivalent to the atom of lime. As the oxalate of lime formed is quite neutral, the oxalic acid united to the lime must be equivalent to an atom of that acid. Thus it appears, that 9 of the crystallized acid is the equivalent for an atom of the acid.

2. The oxalate of lime, formed in the preceding experiment, was collected on a double filter, and after being well washed with distilled water, was dried in a temperature between 90° and 100°; its weight was 10·25 grains. Being kept for some hours in the temperature of 560°, its weight was reduced to 8 grains, and it still possessed all the characters of oxalate of lime. Now, 3·5 grains of the salt were lime; hence, the weight of the oxalic acid necessary to saturate an atom of lime is $8 - 3{\cdot}5 = 4{\cdot}5$. And, since the salt is neutral, 4·5 must be the weight of an atom of oxalic acid.

Atomic weight of the acid.

3. The 4·5 grains constituted the quantity of real oxalic acid in 9 grains of the crystals. The rest of the weight must consist of water. Consequently, oxalic acid crystals are composed of

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Oxalic acid	4·5	= 1 atom
Water	4·5	= 4 atoms
	9	

Thus, the crystals contain just half their weight of water, as was pointed out long ago by Vauquelin.*

* Understanding that a chemical friend, of whose accuracy and information I entertain a very high opinion, had stated, that the uniform result of his experiments was, that the crystals of oxalic acid contain only 3 atoms of water instead of 4, and that they are composed of

1 atom anhydrous acid	4·5
3 atoms water	3·375
	7·875

I was induced to repeat the experiments in the text with every possible attention to accuracy, and to extend them a good deal farther. It may be proper to state here the result of these new experiments.

1. 18 (= 9 × 2) grains of the crystals of oxalic acid were dissolved in water, supersaturated with ammonia, the solution evaporated to dryness in a gentle heat, and the oxalate of ammonia left redissolved in water. 13·5 grains of very pure calcareous spar were dissolved in nitric acid, the solution evaporated to dryness, and the residual salt being heated sufficiently to drive off any excess of acid which it contained, was redissolved in water. These two solutions were mixed together, and after the oxalate of lime had subsided, the clear liquid was tested with muriate of lime and oxalate of ammonia, but was not affected by either, showing that it contained neither lime nor oxalic acid.—This experiment agrees with the one stated in the text; the only difference being the substitution of nitric acid for muriatic acid to dissolve the lime. It shows, that the oxalic acid in 9 grains of the crystals just saturates 3·5 grains of lime, which is equivalent to an atom.

2. The preceding experiment was repeated, with this difference, that, instead of 9 grains of oxalic acid I substituted 8·875 grains of the crystals of oxalate of ammonia:—the result was the same as before—the residual liquid was neither affected by oxalate of ammonia nor muriate of lime. This experiment shows, that 8·875 grains of oxalate of ammonia and 9 grains of oxalic acid crystals, contain the same weight of real oxalic acid.

Oxalate of lime.

4. The oxalate of lime dried at 95° lost 2·25 grains of its weight when kept in the temperature of 560°; and, as the salt continued still neutral, this loss must have been owing to the

3. 9 grains of oxalic acid crystals were dissolved in water, and 6·75 grains of anhydrous carbonate of soda were thrown into the solution: an effervescence took place, and the carbonate gradually diminished in bulk; but the liquid soon became muddy, and the whole carbonate never disappeared though the effervescence completely stopped. I, therefore, evaporated the liquid to dryness in a gentle heat, and pouring water upon the dry salt, digested it for a considerable time on the sand bath. At first the liquid reddened vegetable blues strongly; but the property became gradually weaker and weaker, and after 48 hours' digestion I found the liquid perfectly neutral. From this experiment it appears, that 9 grains of oxalic acid crystals just saturate 4 grains of soda, which is the quantity of that alkali contained in 6·75 grains of anhydrous carbonate.

4. I mixed together solutions of oxalic acid crystals and anhydrous carbonate of potash, in the proportion of 9 grains of the former to 8·75 grains of the latter. This solution, by evaporation, yielded crystals of oxalate of ammonia to the very last drop;—these crystals were neutral, and had the shape and properties of oxalate of potash.

5. 9 grains of the crystals of oxalic acid were dissolved in water, saturated with ammonia, and the solution heated till every trace of ammonia in excess had disappeared. 23·625 grains of crystals of acetate of lead were then dissolved in water with the assistance of heat, and the two solutions were mixed together: the oxalate of lead, which was formed, subsided to the bottom very fast, in consequence of its great weight, and left the supernatant liquid quite transparent and colourless. This liquid was tested with muriate of lime and sulphate of soda, but was not in the least altered by either; showing that it contained no sensible quantity either of oxalic acid or oxide of lead. Now, 23·625 grains of acetate of lead contain just 14 grains of oxide of lead, which is equivalent to an atom. From this experiment, like the former, it follows, that 9 grains of oxalic acid crystals contain just the equivalent for an atom of anhydrous acid.

6. The preceding experiment was repeated, with this difference, that 8·875 grains of crystallized oxalate of ammonia were substituted for the 9 grains of oxalic acid crystals:—the result was the same—the residual liquid contained no oxalic acid or oxide of lead. This is the counterpart of the second experiment, and shows, as it did, that 9 grains of oxalic acid and

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escape of water. Now, 2·25 is equivalent to 2 atoms water. It is obvious from this, that oxalate of lime dried in the temperature of 95° is composed of

1 atom oxalic acid . .	4·5
1 atom lime . .	3·5
2 atoms water . .	2·25
	10·25

5. Such are the atomic weights of oxalic acid and its crystals. Various attempts have been made to determine the constituents of this acid. The first set of experiments on the subject was made by myself, in 1806, and published in the Philosophical Transactions for 1807. I decomposed oxalate of lime by heat, collected and analyzed the products, and concluded that the constituents of oxalic acid were Composition of oxalic acid

Oxygen . . .	64
Carbon . . .	32
Hydrogen . . .	4
	100

8·875 grains of oxalate of ammonia contain the same quantity of oxalic acid.

These experiments leave not the smallest doubt on my mind, that 9 grains of oxalic acid crystals represent the equivalent for an atom of oxalic acid. Now, as it is universally admitted that the atomic weight of oxalic acid is 4·5, there cannot be a doubt that one half of the crystals consist of water, or at least of something which does not enter into combination with bases.

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The next set of experiments on the subject was made by M. M. Gay-Lussac and Thenard. They made up oxalate of lime, dried at the temperature of 212°, into balls with chlorate of potash: these balls were heated to combustion, in a tube, and the gaseous products collected and analyzed. They deduced from these experiments the constituents of oxalic acid as follows:

Oxygen . . .	70·689
Carbon . . .	26·566
Hydrogen . . .	2·745
	100·000*

The data employed in these calculations might be rectified a little, were it not that the salt which they employed still contained a quantity of water of crystallization, which vitiates all the conclusions of these very ingenious experimenters.

Berzelius repeated the experiments of these chemists with his usual precision, and was at very great pains to render his oxalate of lime anhydrous. He obtained from 100 parts of oxalic acid

Oxygen . . .	66·534
Carbon . . .	33·222
Hydrogen . . .	0·244
	100·000

* Recherches Physico-Chemique, II. 299.

Thus, the quantity of hydrogen found by every succeeding experimenter was less than that found by his predecessor. The reason was, that he was at more pains to free the salt operated upon from moisture.

We have no certainty that Berzelius' salt was perfectly anhydrous—it might, and probably did, retain a little water. It occurred to me, that the question of the existence of hydrogen in oxalic acid would be best determined by employing the crystals, which are now known to contain exactly half their weight of water. Nine grains of the crystals were triturated with 200 grains of peroxide of copper, and exposed to a low red heat in a copper tube: to the mouth of this tube was ground a glass tube, filled with fused chloride of calcium, in very small fragments; the extremity of this tube was plunged into the mercurial trough, and the gaseous products were collected in graduated glass jars. By this process, which was originally suggested by Gay-Lussac, the whole of the acid was resolved into carbonic acid gas and water—the water was absorbed by the chloride of calcium, while the carbonic acid gas was collected over mercury. Making allowance for the small quantity of hygrometrical water which peroxide of copper always contains, as was shown by Berzelius, Saussure, and Mr. Walter Crum, the weight of the water retained by the chloride was very nearly 4·5 grains, or just half the weight of

Determined.

the crystals.* The carbonic acid gas evolved amounted to 11·8 cubic inches. Now, the weight of this volume of that gas is 5½ grains; and as carbonic acid is a compound of 2 oxygen + 0·75 carbon, it is evident that 5½ grains contain just 1·5 grain of carbon. From this experiment it appears, that 9 grains of oxalic acid crystals contain

Water . . .	4·5
Carbon . . .	1·5
	6·0

The remaining 3 grains wanting to complete the weight is oxygen, which existed in the acid; but the 4·5 grains of water must be considered as water of crystallization, as it can be driven off from oxalate of lime without destroying the acid. The true constituents of oxalic acid, therefore, are

Carbon . . .	1·5
Oxygen . . .	3
	4·5

But 1·5 is equivalent to 2 atoms of carbon, and 3 is equivalent to 3 atoms oxygen; consequently,

* In some of my experiments I obtained as much as 6·5 grains of water; but I give the average in the text. It is more difficult to determine the water with rigid accuracy than the carbonic acid gas; but I have been led to fix upon 4 atoms, chiefly by the experiments detailed in a preceding part of this section.

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this acid, when anhydrous, must be considered as a compound of

2 atoms carbon . .	1·5
3 atoms oxygen . .	3·0
	4·5

This constitution exactly agrees with the atomic weight of oxalic acid as deduced from the experiments related in the former part of this section. We see that the weight of the oxygen is just double that of the carbon. This agrees with the result of my original experiments—it agrees too, almost exactly, with the proportions of oxygen and carbon given by Berzelius from his own analysis.

It is obvious enough, that if an integrant particle of carbonic acid and an integrant particle of carbonic oxide were to unite together, the compound would be the same, as far as its constituents are concerned, as oxalic acid. For

	OXYGEN.		CARBON.
Carbonic acid is composed of	2	+	0·75
Carbonic oxide . .	1	+	0·75
Total . . .	3	+	1·50

which constitute the very constituents of oxalic acid.

There is a curious experiment of Doboreiner, which deserves to be mentioned, because it corroborates the preceding statements; and seems

to prove, that oxalic acid cannot exist in an insulated state except in combination with water. 5 grains of oxalic acid dried, but still containing a quantity of water, were mixed with 200 grains of fuming sulphuric acid, in an apparatus for receiving gases over mercury: the oxalic acid gradually and totally disappeared, and produced 9·4 cubic inches of gas; the sulphuric acid became less fuming; the gas, washed with ammonia, lost half its volume, which was consequently carbonic acid gas; the residual 4·7 cubic inches were carbonic oxide, for the gas burned with a blue flame, required for complete combustion half its volume of oxygen gas, and formed its own volume of carbonic acid gas. Thus, by the action of sulphuric acid, the water was separated from the acid, and the anhydrous acid was resolved into equal volumes of carbonic acid and carbonic oxide.*

Were the hydrogen detected by Berzelius to be reckoned a constituent of the acid, then the acid would be composed of

Oxygen	3
Carbon	1·5
Hydrogen	0·011
	4·511

Now, 0·011 is only $\frac{1}{10}$th of an atom of hydrogen,

* Annals of Philosophy (second series) III. 315.

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a quantity too small to enter as a constituent into the acid. Berzelius himself considers this acid as composed of

18 atoms oxygen	=	18
12 atoms carbon	=	9
1 atom hydrogen	=	0·125
		27·125

This would raise the atomic weight of the acid to 27·125, a quantity which, by Berzelius' own acknowledgment, is 6 times greater than the truth. In reality his analysis of the acid would give its constitution as follows:

33 atoms oxygen	=	33
22 atoms carbon	=	16·5
1 atom hydrogen	=	0·125
		49·625

And the atomic weight would be 11 times greater than the truth.*

SECT. II.

OF THE ATOMIC WEIGHT OF TARTARIC ACID.

This acid, which is obtained by the decomposition of cream of tartar, forms large but irregular

* Berzelius has lately satisfied himself that oxalic acid contains no hydrogen. See Ann. de Chim. et de Phys. XVIII. 155.

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crystals, which are not altered by exposure to the air. Tartaric acid is much more easily decomposed by heat than oxalic acid; hence, it is apt to acquire a brown tinge, unless great care be taken to crystallize it in rather a low temperature. It is manufactured in the neighbourhood of London, and sold for the use of the calico printers in the state of most beautiful crystals.

1. In the experiments which I formerly published to determine the atomic weight of tartaric acid,* I employed crystals of tartaric acid. These were dissolved in water, and saturated with ammonia, and the atomic weight of the acid was determined by the quantity of nitrate of lead, or carbonate of lime necessary to throw down the whole of the acid; but happening soon after to examine somewhat particularly a quantity of very fine tartaric acid in uncommonly large crystals, prepared I believe by Mr. Luke Howard in the neighbourhood of London, I was struck with an appearance, on breaking one of the crystals, that led me to suspect that water might be mechanically lodged between the plates. The possibility of this having been the case with the crystals which I had employed in my experiments (though much smaller, and carefully pressed between folds of blotting paper) rendered it proper to repeat the whole in

* Annals of Philosophy, (second series) II. 138.

a way not liable to any such suspicions. I shall now relate the results of my new experiments on this subject.

Analysis of tartrate of potash.

2. Tartrate of potash is a salt which crystallizes in large transparent four-sided right prisms with rectangular bases. They contain two atoms of water of crystallization, but are easily rendered anhydrous by heat. A quantity of these crystals was left upon the sand bath for twenty-four hours in a covered glass capsule in a heat amounting for several hours to about 240°; 14·25 grains of the salt, thus rendered anhydrous, were dissolved in distilled water; 20·75 grains of dry nitrate of lead were dissolved in another portion of distilled water, and the two liquids were mixed together: a double decomposition took place, and the tartrate of lead precipitated with such rapidity that in about an hour it left the mother water quite transparent and colourless. This mother water was tested with nitrate of lead and tartrate of potash, without being in the least affected by either. Hence, it contained no sensible quantity either of tartaric acid or of lead. The whole of these two bodies was contained in the precipitate which had fallen.

From this experiment we see that 14·25 grains of anhydrous tartrate of potash contain just the quantity of acid necessary to saturate 14 grains of protoxide of lead, which are contained in the 20·75 grains of nitrate of lead. The tartrate of

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lead was collected on a double filter, washed, and dried in the temperature of about 150°. It weighed exactly 22·25 grains. Now, it contained 14 grains of protoxide of lead; hence, it was composed of

Protoxide of lead	14
Tartaric acid	8·25
	22·25

This tartrate being neutral, and 14 being the weight of an atom of protoxide of lead, it is evident that 8·25 must be the weight of an atom of tartaric acid. We see from this that anhydrous tartrate of potash is composed of

Atom of tartaric acid.

1 atom tartaric acid	8·25
1 atom potash	6
	14·25

For 14·25 grains of it, the quantity employed in the experiment, contained just 8·25 grains of acid.

3. In the experiments described in the Annals of Philosophy, (second series, II. 139.) 9·5 grains of crystallized tartaric acid were saturated with ammonia, and the solution, after being rendered neutral, was mixed with a neutral solution of 6·25 grains of calcareous spar in muriatic acid; and the whole being evaporated to dryness, a quantity of tartrate of lime was obtained which

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weighed (dried at 100°) 12·3 grains. In this experiment there was a small excess of tartaric acid, amounting only to 0·125 grain, and it appears from the result, that this small quantity did not form a sensible precipitate when evaporated to dryness with muriate of lime. The method, therefore, was not delicate enough to decide the atomic weight of tartaric acid; but it is obvious, that the tartrate of lime would consist of 3·5 grains of lime united to 8·25 grains of tartaric acid, and that the excess of the weight above 11·75 must have been water. But this excess is almost exactly half an atom of water; for half an atom of water is 0·5625, and 11·75 + 0·5625 = 12·3125. Now, this differs from 12·3 grains by so small a fraction of a grain, that the whole difference may be safely ascribed to an error in weighing. It appears from this, that when tartrate of lime is dried in a temperature of 100° it retains just half an atom of water.

4. From the preceding experiments, which were several times repeated, it is obvious, that the true atomic weight of tartaric acid is 8·25, and not 8·375, as I formerly stated, misled by some water mechanically lodged between the plates of the crystals. Hence, the crystals must in reality be composed of

Composition of the crystals.

1 atom tartaric acid	8·25
1 atom water	1·125
	9·375

or the weight of an integrant particle of these crystals is 9·375 and not 9·5 as I formerly stated.

Constituents of tartaric acid.

5. When the tartrates are subjected to destructive distillation, they yield a quantity of empyreumatic oil, showing clearly that hydrogen enters as a constituent into the acid. The quantity of carburetted hydrogen and carbonic acid gases evolved, leaves no doubt that carbon and oxygen constitute the other two. Berzelius endeavoured to determine the proportion of these constituents by burning a mixture of tartrate of lead and chlorate of potash in a glass tube, and collecting the products in the manner described in the last section, when treating of the decomposition of oxalic acid. The products obtained were

Hydrogen	3·807
Carbon	35·980
Oxygen	60·213
	100·000 *

Now, if we consider it as a compound of

2 atoms hydrogen	=	0·25	or	3·030
4 atoms carbon	=	3	-	36·364
5 atoms oxygen	=	5	-	60·606
		8·25		100

we find its constituents just give the true ato-

* Annals of Philosophy, V. 95.

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mic weight of the acid, while the composition per cent. agrees very nearly with the results of Berzelius. The agreement would be still nearer were we to correct the data by which Berzelius calculated the constituents: for the true weight of the hydrogen which he obtained was not 3·807, but 3·641 per cent. A very slight trace of water derived from some unknown source would easily account for the slight surplus of hydrogen.

6. As the quantity of water in crystals of tartaric acid is accurately known, it occurred to me that a more accurate idea might be formed of the constituents of this acid, by analyzing the crystals, than by any tartrate whatever. Accordingly, a quantity of the acid was reduced to a fine powder, and being placed between the folds of a quantity of blotting paper, was subjected to a considerable pressure for twenty-four hours, in order to get rid of the hygrometrical water. 9·375 grains of this powder were triturated with 200 grains of peroxide of copper, and the mixture being put into a copper tube, was exposed to a red heat, under similar circumstances with the oxalic acid, the analysis of which was related in the preceding section. The weight of the water obtained was almost exactly 3·375 grains,* while the volume of carbonic acid was just

* In some of my experiments the quantity of water extricated was 4·85 grains; but I give in the text the average of a number of trials.

double that procured from 9 grains of crystallized oxalic acid.

Now, the 9·375 grains analyzed contained 1·125 grain of water. The residual 2·25 grains of water indicate 0·25 of hydrogen. The quantity of carbonic acid evolved showed that the carbon in 9·375 of tartaric acid crystals is just double that in 9 grains of oxalic acid crystals. But we have seen in the last section, that the carbon in 9 grains of the crystals of the latter acid is 1·5 grain: consequently, 9·375 grains of crystallized tartaric acid contain 3 grains of carbon. The 5 grains wanting to make up the weight must be oxygen. Thus it appears, that the constituents of 9·375 grains of crystallized tartaric acid are as follows:

1 atom water	=	1·125
2 atoms hydrogen	=	0·25
4 atoms carbon	=	3
5 atoms oxygen	=	5
		9·375

Some years ago, Dr. Prout gave me the result of a set of experiments which he had made, to determine the composition of tartaric acid in crystals. The table which he gave me was as follows:

3 atoms hydrogen	0·375
4 atoms carbon	3
6 atoms oxygen	6
	9·375

This result agrees exactly with the preceding one of my own. Had I been aware of Dr. Prout's result when I published my first experiments on the atomic weight of tartaric acid, it would have induced me to have paused before I stated the integrant particle of these crystals to weigh 9·5. But I had forgotten the statement of Dr. Prout, till I accidentally met with it after all my experiments on this acid were finished. I mention it now, as affording a strong corroboration of the accuracy of the atomic weight of this acid as now determined: for my opinion of Dr. Prout's precision is so high, that I am disposed to place much value upon all his investigations; for I have had an opportunity of judging of the uncommon care with which all his experiments are performed.

SECT. III.

OF THE ATOMIC WEIGHT OF CITRIC ACID.

Though the taste of citric acid in crystals is as intensely acid as that of tartaric or even oxalic acid, yet it acts with less energy upon other bodies, and does not so easily decompose other salts as these two acids do. Thus, when we mix oxalate or tartrate of ammonia with a solution of muriate of lime, oxalate or tartrate of lime imme-

diately precipitates. But citrate of ammonia produces no such effect; yet citrate of lime is insoluble in water, as well as the other two calcareous salts. Citrate of ammonia does not occasion a precipitate in nitrate of lead, although citrate of lead is quite insoluble in water. But oxalate and tartrate of ammonia precipitate lead with great energy. This acid is seldom employed by chemists as a reagent, and of course, is of inferior importance in a chemical point of view. But it exists so abundantly in the vegetable kingdom, constituting a portion of so many fruits, that a knowledge of its nature and constitution, constitutes an interesting problem in vegetable physiology. In my experiments to determine the atomic weight of this acid, I was directed by those which Berzelius had published in 1815.*

Atomic weight of citric acid.

1. 9·5 grains of the crystals of citric acid were dissolved in water, saturated with ammonia, and the solution deprived of all excess of ammonia by evaporation. 20·75 grains of dry nitrate of lead were dissolved in another portion of distilled water, and the two solutions were mixed together. No precipitate appearing, and no indication of a double decomposition taking place, the liquid was slowly evaporated to dryness. Water being digested upon the dry resi-

* Annals of Philosophy, V. 93.

due, nitrate of ammonia was dissolved, while an insoluble citrate of lead remained behind. The aqueous solution, even when very much concentrated, was not affected by sulphate of soda, showing that it contained no lead. A portion of it being mixed with some liquid nitrate of lead, and the mixture being evaporated gently to dryness, and the residue being digested in water, a complete solution took place without the appearance of any citrate of lead whatever. This shows that the liquid contained no sensible quantity of citric acid.

From the preceding experiment it follows, that 9·5 grains of citric acid crystals contain a quantity of citric acid just capable of saturating all the protoxide of lead in 20·75 grains of nitrate of lead, which amount to exactly 14 grains. The citrate of lead was carefully collected upon a double filter, well washed, and dried, first in the open air, and then in a temperature not exceeding 150°—its weight was 21·25 grains. Now, of this weight, 14 grains were protoxide of lead; the remainder must be citric acid. Thus citrate of lead, dried in 150°, is a compound of

Citric acid . .	7·25
Protoxide of lead .	14
	21·25

This citrate being neutral, and 14 being the ato-

mic weight of protoxide of lead, it is clear that 7·25 is the atomic weight of citric acid.

Composition of the crystals.

2. But the weight of the crystallized citric acid employed was 9·5 grains. The excess of weight of these crystals above 7·25 must be owing to combined water. This excess is 2·25, which is equivalent to the weight of 2 atoms of water. Hence it follows, that crystallized citric acid is a compound of

1 atom real acid	.	7·25
2 atoms water	.	2·25
		9·5

3. I find, when 9·5 grains of crystallized citric acid are exposed to a heat rather below 212°, they lose very nearly 0·73 grain of their weight, and fall down in the state of a powder. Now, 0·73 is ⅓d of 2·25; so that, by the application of heat, these crystals give out just the third of their water,—and no more can be driven off without, at the same time, decomposing the acid; for its colour is rendered brown, and a peculiar odour becomes sensible.

Constituents of citric acid.

4. Berzelius decomposed citric acid by mixing 1 part of citrate of lead with chlorate of potash, burning the mixture in a glass tube, and collecting the products. He deduced from this analysis that the constituents of citric acid per cent. are

Hydrogen	3·800
Carbon	41·369
Oxygen	54·831
	100

Now, if we suppose the constituents to be

2 atoms hydrogen	= 0·25	or	3·448
4 atoms carbon	= 3	-	41·379
4 atoms oxygen	= 4	-	55·173
	7·25		100·000

the weight of the atom of the acid will be 7·25, as indicated by the preceding experiments; while the constituents per cent. agree very nearly indeed with those given by Berzelius from his experiments.

5. It occurred to me that, as the quantity of water in the crystals of citric acid had been accurately determined, the analysis of a given weight of these crystals would give the most satisfactory evidence of the true constituents of this acid. 9·5 grains of the crystals, in the state of a fine powder, were well triturated with 200 grains of peroxide of copper, and exposed to a red heat in a copper tube, with all the necessary precautions to collect the whole of the products. The weight of the water retained by the chloride of calcium approached nearly to 4·5 grains;*

* The average of my own experiments gave the amount of water from 9·5 grains of citric acid crystals only 4·15 grains. It was a comparison of my experiments with those of Berzelius that induced me to state 4·5 grains as the amount of the water.

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and the very same volume of carbonic acid gas came over as when 9·375 grains of tartaric acid crystals were decomposed in the same manner. 4·5 water indicate 4 atoms of that liquid; but the crystals contain 2 atoms of water;—consequently, the other 2 atoms were formed by the decomposition of the acid, and they indicate 2 atoms of hydrogen. The carbon, being the same as in tartaric acid, amounts to 4 atoms, the weight of which is 3. The weight necessary to make up the whole 9·5 of citric acid decomposed must be oxygen. Thus it appears, from the preceding analysis, that 9·5 of citric acid crystals are composed of

2 atoms water	.	2·25
2 atoms hydrogen	.	0·25
4 atoms carbon	.	3·00
4 atoms oxygen	.	4·00
		9·5

Thus, both the atomic weight and the constituents of the acid are confirmed by this analysis.

SECT. IV.

OF THE ATOMIC WEIGHT OF ACETIC ACID.

THE determination of the atomic weight of this acid is attended with peculiar difficulties, be-

cause it forms no insoluble salts. On this account, we cannot have recourse to the method of double decomposition, which has answered so well in many of the investigations communicated in the preceding pages of this work. Before proceeding farther, I must express my obligations to two of my friends, both of them chemical manufacturers in Glasgow, I mean Mr. Charles M'Intosh and Mr. Ramsay; the former of whom furnished me with liquid acetic acid in a state of perfect purity, while the latter gave me a pure hydrated acetic acid, in the state of crystals. Had it not been for the purity of the acids thus furnished me, I should have been under the necessity of relinquishing this acid in despair.

Analysis of acetate of soda by Berzelius.

1. Berzelius analyzed several of the acetates with his accustomed care and accuracy, and was at great pains to obtain them quite free from water; but, unfortunately, there is no criterion by which we can determine whether we have rendered a salt perfectly anhydrous or not, unless it be a substance capable of bearing a red heat, which is far from being the case with any of the acetates. It is the freeing these salts from water which constitutes the great difficulty in analyzing them; but Berzelius' experiments are made with such scrupulous attention to accuracy, that they deserve peculiar notice. They will certainly furnish us with pretty near

approximations. He found the constituents of acetate of soda as follows:

Acetic acid .	36·995	or	6·448
Soda .	22·895	-	4
Water . .	40·11	-	7·007
	100·00*		

Now, this salt is perfectly neutral; hence it must consist of an atom of acetic acid and an atom of soda united together, with a certain number of atoms of water of crystallization. The numbers in the second column exhibit the atomic weights calculated from the analysis: 4 is the atomic weight of soda, and 7·007 approaches nearly to 6·75, which is the weight of 6 atoms of water; 6·448 is the weight of an atom of acetic acid according to this analysis. We may conclude, then, that crystallized acetate of soda is a compound of

1 atom acetic acid,
1 atom soda,
6 atoms water.

And the atomic weight of acetic acid, deduced from Berzelius' analysis of this salt, is 6·448.

As we have hitherto found that the atomic weights of all the acids and bases are multiples

* Ann. de Chim. LXXXII. 113. Correcting his estimate of soda.

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of 0·25, it is exceedingly probable that the atomic weight of acetic acid is either 6·25 or 6·5, as Berzelius' number lies between these. That I might be able to determine which of these two numbers was the real atomic weight of acetic acid, I dissolved 6·75 grains of anhydrous carbonate of soda in distilled water, saturated the solution with very pure acetic acid, and evaporated the solution to dryness, by means of a gentle but long continued heat. The dry salt thus obtained, which was in an eight ounce phial, was kept for four hours upon the sand bath, in a heat which was as nearly as possible 550°. I was obliged to repeat this experiment a great many times, before I made myself acquainted with the limit of the temperature which the salt is capable of bearing without decomposition. The heat must be sufficient to keep the salt in a state of fusion, otherwise the whole water is not driven off—if it be as high as 600° decomposition takes place. While the salt is in fusion it has a darkish colour, but it becomes beautifully white as soon as it congeals, if none of the acid has been destroyed. In two successive experiments, which were quite successful, the weight of the salt was 10·25 grains: now, 6·75 grains of anhydrous carbonate of soda contain just 4 grains of soda; consequently, anhydrous acetate of soda is composed of

By the author.

Soda	4
Acetic acid . . .	6·25
	10·25

The salt, after this treatment, was still neutral. We see, therefore, that the true atomic weight of acetic acid is 6·25; and the true constituents of crystallized acetate of soda must be

1 atom acetic acid	6·25	or per cent.	36·764
1 atom soda .	4	- -	23·529
6 atoms water	6·75	- -	39·706
	17		

And these numbers approach so near those of Berzelius, that they may be said to confirm one another.

Analysis of acetate of lead.

2. Acetate of lead is a neutral salt, which can be easily procured in beautiful crystals, and in a state of the greatest purity. Hence, an accurate analysis of it will furnish us with very good data for determining the atomic weight of acetic acid.

Berzelius published an analysis of this salt a good many years ago, which approaches very near the truth, though not sufficiently so to give the correct atomic weight of acetic acid.

(1.) I followed his method of freeing the salt of water, by placing it over a flat glass vessel containing concentrated sulphuric acid in the vacuum of an air-pump: 23·625 grains of the

crystals when thus treated, lost almost exactly 3·375 grains of water—which is equivalent to 3 atoms of that liquid.

(2.) It will be shown in a subsequent chapter of this work, that crystallized oxalate of ammonia is composed of

1 atom oxalic acid .	4·5
1 atom ammonia .	2·125
2 atoms water . .	2·25
	8·875

8·875 grains of crystallized oxalate of ammonia were dissolved in a minimum of distilled water; in another portion of the same liquid, I dissolved 23·625 grains of beautiful semitransparent crystals of acetate of lead: the two solutions being mixed, a double decomposition took place, and oxalate of lead precipitated to the bottom in a very fine powder, leaving the supernatant liquid quite transparent and colourless. This liquid being tested by sulphate of soda and muriate of lime, was not in the least affected by either of these reagents; showing that it contained no sensible quantity either of oxide of lead or of oxalic acid. From this experiment it is evident, that the oxalic acid in 8·875 grains of oxalate of ammonia just saturates the oxide of lead in 23·625 grains of acetate of lead. The oxalate of lead, which had precipitated, was carefully collect-

ed on a double filter, and being washed and dried in a temperature not quite so high as 212°, weighed as nearly as possible 18·5 grains. Now, 4·5 of this weight were oxalic acid; consequently, the protoxide of lead in 23·625 grains of acetate of lead is precisely 14 grains. The portion of the salt wanting to make up the total weight of 23·625, is obviously acetic acid. Thus it appears, from the preceding analysis, that acetate of lead is composed of

Acetic acid . .	6·25
Protoxide of lead .	14·00
Water . . .	3·375
	23·625

The salt being neutral, and 14 being equivalent to the weight of an atom of protoxide of lead, and 3·375 to that of 3 atoms of water, it is obvious that 6·25 must represent the atomic weight of acetic acid.

Acetate of lime.

3. I made some experiments upon the acetate of lime; but found that it cannot be rendered anhydrous without exposing it to a temperature so high that the acid is partially driven off or decomposed. At the temperature of 450°, the salt retains about the third of an atom of water. Berzelius kept the salt for some time in the highest temperature which it could bear: it appears from the result of his analysis, that when

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thus treated, it still retains nearly the eighth of an atom of water.*

Analysis of acetic acid.

4. Berzelius analyzed acetic acid by burning a mixture of chloride of potash and anhydrous acetate of lead in a glass tube, and collecting the products. The water formed, and carbonic acid gas collected, together with the known weight of acid in 1·06 of acetate of lead employed, give us the constituents of the acid. The acid in 1·06 of dry acetate of lead is 0·332; he obtained 0·18 of water, indicating 0·02 hydrogen; and 0·574 carbonic acid, indicating 0·15654 of carbon. Thus the constituents of the acid were

Hydrogen	0·02	or per cent.	6·0240
Carbon	0·15654	- -	47·1506
Oxygen	0·15546	- -	46·8254
	0·33200		100·0000

Now, if we consider the constituents of this acid to be

2 atoms hydrogen	0·25	or	4
4 atoms carbon .	3	-	48
3 atoms oxygen .	3	-	48
	6·25		100

we have the atomic weight as determined in the preceding part of this section; while the constituents per cent. deviate very little from those of

* Annals of Philosophy, V. 174.

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Berzelius. It is obvious from the analysis of Berzelius, that the weights of the carbon and oxygen in the acid are the same; consequently, there must be 4 atoms of the former for 3 of the latter. The hydrogen found by Berzelius would indicate 3 atoms of hydrogen instead of 2. This was, no doubt, owing to the introduction of a very small quantity of water from some unknown source—an accident against which it is extremely difficult to provide.

I have not repeated the analysis of acetic acid, considering the result obtained by Berzelius as sufficient (together with the knowledge of the atomic weight) to determine the composition of this acid. The most accurate method of proceeding would be to employ the crystals of acetate of lead, without depriving them of their water of crystallization. This water has been shown to amount to 3 atoms, and it must be allowed for in the calculation; the quantity of salt which should be employed is 23·625 grains, which is equivalent to an integrant particle.

Crystals of acetic acid

5. It has been long known that, when dry acetate of soda and sulphuric acid are mixed in the requisite proportions, and distilled in a retort, an acetic acid comes over so strong that it crystallizes when cooled down to a low temperature, and remains in crystals as long as the thermometer is lower than 50°. If we have a considerable quantity of the acid in this concentrat-

ed state, we have it in our power, by pouring the liquid portion off the crystals, to obtain them in a state of great purity, and quite dry. It is in this way that crystallized acetic acid is prepared by Mr. Ramsay of Glasgow. By drying these crystals on blotting paper, at a low temperature, I freed them completely from all adhering liquid, and made them as dry as the crystals of tartaric acid.

Putting a quantity of these dry crystals into a phial, I melted them by leaving them for 24 hours in a warm room. The liquid thus obtained did not crystallize, though kept for a long time in a temperature as low as 40°; but if we raise it to the temperature of 45°, and throw into it a single crystal of acetic acid, a number of crystalline spiculæ dart out with rapidity all over the liquid, and the temperature rises from 45° to 51°. By degrees, after this commencement of crystallization, the whole liquid assumes the solid form, although the temperature be not lower than 45°.

These crystals, while in a liquid state, and at the temperature of 60°, have a specific gravity of 1·06296.

6. I dissolved 22·125 grains of these crystals in water, and added to the solution 26·25 grains of anhydrous carbonate of potash, obtained by exposing bicarbonate of potash to a red heat. This addition just neutralized the acid, for the

Contain one atom of water.

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mixture produced no change upon the colour of litmus or cudbear paper. If we divide each of the substances employed by 3, the consequences which I mean to draw from the experiment will be plainer.

$$\frac{22{\cdot}125}{3} = 7{\cdot}375\text{; and}$$

$$\frac{26{\cdot}25}{3} = 8{\cdot}75$$

We may say, then, that 7·375 grains of crystals of acetic acid were just neutralized by 8·75 grains of anhydrous carbonate of potash; but 8·75 grains of this carbonate contain just 6 grains of potash, which is equivalent to an atom. Consequently, 7·375 grains of the crystals of acetic acid must contain just 6·25 grains of real acetic acid; for that is the quantity requisite to saturate 6 grains of potash. The remainder of the weight of the acid is obviously water, and it amounts to 1·125, which is equivalent to an atom of water. Thus it appears that the crystals of acetic acid are composed of

1 atom real acid	.	6·25
1 atom water	.	1·125
		7·375

They do not contain 2 atoms of water, as I formerly supposed, misled by the statements of Mollerat, which I find to be inaccurate.

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7. By dissolving given weights of these crystals in water, and taking the specific gravity of the solutions at 60°, I was enabled to form the following table, exhibiting the specific gravity of various atomic compounds of this acid and water:

Table exhibiting the specific gravity of acetic acid of different strengths.

ACID.		WATER.		SP. GR. AT 60°.
1 atom	+	1 atom	.	1·06296
1 -	+	2 -	.	1·07060
1 -	+	3 -	.	1·07084
1 -	+	4 -	.	1·07132
1 -	+	5 -	.	1·06820
1 -	+	6 -	.	1·06708
1 -	+	7 -	.	1·06349
1 -	+	8 -	.	1·05974
1 -	+	9 -	.	1·05794
1 -	+	10 -	.	1·05439

We see from this table that the specific gravity of the liquid is a maximum, when it consists of 1 atom acid united to 4 atoms water; or, when it is composed of

Acid	. 6·25	or 100	or	58·1395
Water	. 4·5	- 72	-	41·8605
				100

We see, too, that the specific gravity of acid, containing only 1 atom water, is nearly the same with that containing 7 atoms water; or the two following compounds

1.	Acid	6·25	or	100	or	84·7457
	Water	1·125	-	18	-	15·2543
2.	Acid	6·25	or	100	or	44·2477
	Water	7·875	-	126	-	55·7523

have nearly the same specific gravity. It is obvious from this, that the specific gravity of an acetic acid does not assist us in determining its strength, or the true quantity of acid which it contains.*

SECT. V.

OF THE ATOMIC WEIGHT OF SUCCINIC ACID.

This acid, as it is at first obtained by the distillation of amber, has a yellow colour, and an empyreumatic smell, both of which are removed by digesting it in nitric acid, which decomposes the oily matter with which it was contaminated. When thus purified, its colour is very white, and it crystallizes in four-sided prisms. I do not find it to contain any water of crystallization. The crystals consist entirely of anhydrous acid.

* In the two last editions of my System of Chemistry (Vol. II. p. 141.) I inserted a table, exhibiting the specific gravity of acetic acid of various strength, deduced from the experiments of Mollerat. That table is quite erroneous, as may be seen by comparing it with the one now given.

1. To determine the atomic weight of this acid, 6·25 grains of the crystals were dissolved in water, and neutralized by ammonia. 17·375 grains of the crystals of protosulphate of iron were dissolved in water, and the iron peroxidized by digesting the solution, mixed with a little nitric acid. The brown coloured liquid thus obtained was rendered as neutral as possible by ammonia. These two solutions being mixed together, a double decomposition took place, and succinate of iron precipitated in abundance. The whole being thrown upon a double filter, the succinate of iron was retained, and the liquid which passed through was transparent and colourless. This liquid was not rendered blue by prussiate of potash—showing that it contained no sensible quantity of iron. Neither was it precipitated or altered by ammonia, or by persulphate of iron; the last of which salts would have occasioned a precipitate, if it had contained any succinic acid. Atomic weight of succinic acid.

From this experiment it appears, that 6·25 grains of succinic acid just saturate all the peroxide of iron from 17·375 grains of protosulphate of iron. Now, it was shown in a former section of this work, that 17·375 grains of protosulphate of iron contain just 4·5 grains of protoxide, which is equivalent to 5 grains of peroxide of iron.

The succinate of iron, precipitated in the Succinate of iron.

preceding experiment, being well washed, and dried in the temperature of 212°, weighed 11·25 grains; and it was obviously composed of

Succinic acid	6·25	or	0·555
Peroxide of iron	5	-	0·444
			1·000

The salt being neutral, and five being the atomic weight of peroxide of iron, 6·25 must be the atomic weight of succinic acid.

Thus it appears, that acetic and succinic acid have the same atomic weights; yet scarcely any two acids differ more from each other in their properties. Acetic acid is so soluble in water that it is difficult to obtain it in the state of crystals, and these crystals cannot exist, unless they contain an atom of water united to an atom of acid; but succinic acid requires nearly 100 times its weight of water to dissolve it, and its crystals contain no water whatever. There is some analogy, however, in the way in which the two acids combine with bases. Thus, acetic acid unites with 1 atom and with 2 atoms of protoxide of lead, and so does succinic acid. Probably many other similar analogies would be discovered if the succinates were better known than they are at present.

Composition of succinic acid.

2. I have not made any experiments upon the constituents of this acid, because I considered

the analysis of Berzelius as sufficiently decisive. He mixed 1·294 of anhydrous succinate of lead with chlorate of potash, and burned it in a glass tube, collecting the product. The water formed was 0·1536, and the carbonic acid 0·7.

Now, 1·294 succinate of lead contain 0·40215 of succinic acid; 0·1536 water contain 0·01706 hydrogen, and 0·7 carbonic acid contain 0·19091 carbon. What is wanting besides these constituents to make up the weight of the succinic acid is oxygen. Thus, the constituents of succinic acid are

Hydrogen	0·01706	or	0·2651
Carbon	0·19091	-	2·9670
Oxygen	0·19418	-	3·0179
	0·40215		6·2500*

The second column in which the constituents are reduced to what they would be, if 6·25 or an atom of succinic acid had been decomposed, approach so nearly to

2 atoms hydrogen	0·25
4 atoms carbon	3
3 atoms oxygen	3
	6·25

that we cannot hesitate to admit that these represent the atomic constituents of succinic acid.

* Annals of Philosophy, V. 99.

Thus it appears, not only that the atomic weight of succinic acid is the same with that of acetic acid, but that both acids are composed of the very same atomic constituents. This is a decisive proof that these vegetable acids are not formed immediately by the combination of all their atomic constituents together; but that they consist of certain binary or ternary combinations combined together. For example, we might suppose one of these acids formed by the union of

		OXYGEN.		CARBON.		HYDROGEN.
1 atom carbonic acid	=	2	+	1	+	0
1 atom carbonic oxide	=	1	+	1	+	0
2 toms olefiant gas	=	0	+	2	+	2
		3	+	4	+	2

and the other of

1 atom oxalic acid	=	3	+	2	+	0
2 atoms olefiant gas	=	0	+	2	+	2
		3	+	4	+	2

for such combinations would give the atomic proportions, and yet they might constitute compounds possessed of very different properties. These constituents are not given from any idea that they constitute the true secondary elements of the acids in question, but only to help to enable the reader to conceive how two acids may have the same elements, and yet possess

very different properties; but this difficult subject stands in need of farther investigation.

3. Succinic acid furnishes a very easy method of separating iron from other bodies with which it is mixed in acid solutions, and determining its quantity—a method proposed many years ago by M. Gehlen. The method is this: Peroxidize the iron in the solution by digesting it with some nitric acid. Then make the solution as neutral as possible by means of ammonia. Succinate of ammonia will now precipitate the iron in red coloured flocks. Separate the precipitate upon a double filter, wash it well, and dry it in the temperature of 212°; $\frac{1}{3}$ths of the weight of this precipitate is peroxide of iron, and the remaining $\frac{2}{3}$ths are succinic acid.

SECT. VI.

OF THE ATOMIC WEIGHT OF BENZOIC ACID.

This acid, like the preceding, is obtained by sublimation, and its crystals, like those of succinic acid, are free from water. There is therefore little difficulty in determining its atomic weight.

1. Fifteen grains of the crystals were dissolved in distilled water by means of ammonia, and the solution was concentrated on the sand bath till

Atomic weight of benzoic acid.

all excess of ammonia was driven off. 17·375 grains of crystallized protosulphate of iron were dissolved in water, the oxide was peroxidized, and the solution rendered neutral precisely in the manner described in the last section. These two solutions being mixed, a double decomposition took place, and benzoate of iron immediately precipitated in buff coloured flocks. This precipitate was separated by means of a double filter. The liquid which passed through was transparent and colourless, and was not in the least altered by prussiate of potash, nor was any precipitate occasioned by the addition of persulphate of iron, showing that it contained no sensible quantity of iron, or of benzoic acid.

From this experiment we learn that 15 grains of benzoic acid just neutralize 5 grains of peroxide of iron. And as 5 represents the atomic weight of peroxide of iron, 15 must be the atomic weight of benzoic acid.

Benzoate of iron.

2. The benzoate of iron formed in the preceding experiment being dried in the temperature of 212°, weighed exactly 20 grains. It was therefore anhydrous, and consisted of

1 atom benzoic acid	15
1 atom peroxide of iron	5
	20

Hence, the fourth part of this precipitate is peroxide of iron and the other three-fourths ben-

zoic acid. Benzoate of soda or ammonia was proposed by Hizinger as an excellent reagent for separating iron from other bodies; and I find it to answer just as well as succinate of soda. The method of proceeding with both salts is precisely the same.

Composition of benzoic

3. Benzoic acid, like acetic and succinic acids, combines with protoxide of lead in two proportions, forming a salt composed of 1 atom acid and 1 atom protoxide, and another composed of 1 atom acid and 3 atoms protoxide. Berzelius found that when a mixture of benzoate of lead and chlorate of potash was burned in the way formerly described in glass tubes, a portion of the acid was apt to sublime without decomposition. This did not happen so readily when the sub-benzoate of lead was employed. The analysis of a quantity of sub-benzoate containing 0·317 of benzoic acid gave 0·1414 water, equivalent to 0·01571 hydrogen; and 0·8645 carbonic acid, equivalent to 0·23577 carbon. Consequently, the constituents of benzoic acid are

Hydrogen	0·01571	or	0·75
Carbon	0·23577	-	11·15
Oxygen	0·06552	-	3·10
	0·31700		15·00*

The second column, which exhibits the propor-

* Annals of Philosophy, V. 181.

tions of the constituents, answering to the atomic weight 15 of the acid approaches so very nearly to

6 atoms hydrogen	0·75
15 atoms carbon	11·25
3 atoms oxygen	3
	15

that we can have no hesitation in admitting that these represent the true atomic constituents of the acid. It is therefore a very complicated body, as it contains no fewer than 24 atoms. Like all other very complex bodies its affinities are very weak.

SECT. VII.

OF THE ATOMIC WEIGHT OF SACLACTIC ACID.

I HAVE prepared this acid both from sugar of milk and from gum. The acid obtained from gum is always contaminated with saccolate of lime; the best way of freeing it from which is to dissolve it in water. The saccolate of lime remains behind, and may be separated by the filter. Then by evaporating the aqueous solution to dryness by a gentle heat, we recover the saclactic acid in a state of purity. But great care must be taken not to expose the evaporat-

Purification of saclactic acid.

ing liquid to too high a temperature; for the saclactic acid is very easily rendered brown, indicating the looseness with which its elements are combined. The saclactic acid from sugar of milk is quite pure as at first prepared.

Saclactic acid has a fine white colour when dried in a temperature sufficiently low. Its taste is only slightly acidulous, but it acts powerfully on vegetable blues, reddening them with considerable energy. It is but little soluble in water, though boiling water dissolves a greater portion than cold water; and if a saturated solution of this acid in boiling water be set aside, the greatest part of the acid is deposited as the water cools in the state of small crystals.

Saclactate of soda analyzed.

1. To determine the atomic weight of this acid, I employed saclactate of soda;—a salt which I formed by saturating sesquicarbonate of soda with saclactic acid. The acid dissolved in the liquid with effervescence, and I continued to add new portions of the acid till the effervescence was at an end. The liquid was then passed through a filter, to separate a portion of undissolved acid. Being left for twenty-four hours, it had deposited an additional portion of saclactic acid, yet it still reddened vegetable blues. Being gently evaporated to dryness, it deposited the saclactate of soda in white semitransparent crystals, consisting of four-sided rectangular prisms with square bases. The taste of this salt

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is slightly saline, and somewhat similar to that of phosphate of soda. It is not very soluble in water, and is very easily rendered brown, unless great care be taken in regulating the heat to which it is exposed.

22·625 grains of these crystals were dissolved in water, and the liquid mixed with a solution of 20·75 grains of nitrate of lead. A double decomposition took place immediately, and saclactate of lead was precipitated in abundance. The clear supernatant liquid was tested by sulphate of soda and nitrate of lead, but was not in the least affected by either; showing, that it contained no sensible quantity of lead or of saclactic acid.

The saclactate of lead being collected on a double filter, washed and dried in a temperature not exceeding 212°, weighed 27 grains. Now, it contained all the protoxide of lead existing in 20·75 grains of nitrate of lead, amounting to 14 grains. It was therefore composed of

Protoxide of lead	14
Saclactic acid	13
	27

From this experiment it follows that 22·625 grains of crystallized saclactate of soda contain 13 grains of saclactic acid. As these 13 grains just saturated 14 grains of protoxide of lead, which is the equivalent for an atom, it is obvious

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that in the saclactate of soda they must have been in combination with an atom of soda, the equivalent for which is 4 grains. The remaining 5·625 grains, still remaining to make up the weight of the salt, must have been water; and this weight is equivalent to 5 atoms water. Thus it appears, that saclactate of soda is composed as follows:

1 atom saclactic acid	13
1 atom soda	4
5 atoms water	5·625
	22·625

It is obvious that 13 represents the atomic weight of this acid. Atom of saclactic acid.

2. Berzelius analyzed saclactic acid by the same process as the other vegetable acids. 1 part of saclactate of lead, equivalent to 0·4814 of saclactic acid, when burned with chlorate of potash, gave out 0·21 water, equivalent to 0·0233 hydrogen; and 0·594 carbonic acid, equivalent to 0·1620 carbon.* From this it follows, that the constituents of saclactic acid are Constituents of saclactic acid.

Hydrogen	0·0233	or	0·6292
Carbon	0·1620	-	4·3747
Oxygen	0·2961	-	7·9961
	0·4814		13·0000

* Annals of Philosophy, V. 180.

The second column, exhibiting the proportion of the constituents in 13 of the acid, which is the atomic weight, approaches nearest to

4 atoms hydrogen . .	0·5
6 atoms carbon . .	4·5
8 atoms oxygen . .	8·0
	13·0

The greatest deviation is in the hydrogen, which is about $\frac{1}{8}$th part too high, while the carbon is rather more than $\frac{1}{13}$th part too low. The proportion of oxygen is almost exact.

Berzelius analyzed, likewise, 0·333 parts of saclactic acid in the same way. He obtained 0·149 of water, equivalent to 0·01655 hydrogen; and 0·393 carbonic acid, equivalent to 0·10718 carbon.* Hence, the constituents of the acid, according to this analysis, are

Hydrogen . .	0·01655	or	0·64
Carbon . .	0·10718	-	4·18
Oxygen . .	0·20960	-	8·18
	0·33333		13·00

We perceive, from the second column exhibiting the proportion of the constituents in 13 parts, or an atom of the acid, that the proportion, both of hydrogen and oxygen, is greater in this analysis than in the preceding. No doubt, the reason

* Annals of Philosophy, V. 180.

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was that the saclactic acid contained a greater proportion of adhering water than the saclactate of lead; though even the saclactate of lead was, probably, not absolutely free from water—unless, indeed, the small excess of water in that analysis was derived from some other accidental source—as the moisture of the air when the ingredients happened to be mixed together. Upon the whole, these analyses of Berzelius come wonderfully near the truth, and do much honour both to the sagacity and skill of this most indefatigable chemist.

SECT. VIII.

OF THE ATOMIC WEIGHT OF FORMIC ACID.

Though formic acid was discovered by Margraff, and several of its properties pointed out, it is only of late years that very correct notions respecting it have been attained. Fourcroy and Vauquelin endeavoured to prove, in 1802, that it was merely a mixture of acetic and malic acids; but this opinion was refuted, and the peculiar nature of formic acid established by Suersen, and Gehlen. Dobereiner has lately pointed out some properties by which this acid may be readily distinguished from every other.

1. Formic acid, as far as is known at present, cannot be obtained in the state of crystals, but Properties of formic acid.

only in solution in water. It is as volatile as acetic acid, and has a smell somewhat similar to that of that acid. It was this similarity of smell, and the property which it has of forming soluble salts with most of the bases, that led Fourcroy and Vauquelin to the opinion that it was identical with acetic acid.

Dobereiner has ascertained, that when formic acid is mixed with concentrated sulphuric acid, it undergoes decomposition at the ordinary temperature of the atmosphere—being converted into water, which combines with the sulphuric acid, and into carbonic oxide, which makes its escape in the form of gas. When it is mixed with nitrate of silver or nitrate of mercury, and a gentle heat applied, the formic acid is equally decomposed; carbonic acid is disengaged, and the oxides are reduced to the metallic state. These curious phenomena are easily observed, and they are sufficient to enable us to distinguish this acid from every other.*

Analysis of formic acid.

2. Berzelius was the first chemist who attempted to determine the composition of formic acid. He found† that anhydrous formate of lead is a compound of

Formic acid	100	or	4·696
Protoxide of lead	298·1	-	14

* Gilbert's Annalen der Physick, LXXI. 107.

† Annals of Philosophy, IX. 107

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According to this analysis the atomic weight of formic acid is 4·696. Now, the nearest multiple of 0·125 to this is 4·625. Hence, the probability is, that this number represents the true atomic weight. Berzelius analyzed the acid by burning a certain proportion of formate of lead and chlorate of potash in a glass tube, precisely in the way formerly described. He found the constituents, by this process, to be

Hydrogen	2·84	or	0·13135
Carbon	32·40	-	1·49850
Oxygen	64·76	-	2·99515
	100·00		4·62500

The second column, showing the weight of each constituent in 4·625, or an atom of the acid, approaches so nearly to

1 atom hydrogen	0·125
2 atoms carbon	1·5
3 atoms oxygen	3
	4·625

that we can have little reason to hesitate about adopting these as the true atomic constituents of the acid. The only difference between its atomic constitution and that of oxalic acid, is, that formic acid contains an atom of hydrogen which is wanting in oxalic acid. But the loose manner in which the constituents of this acid are held

together, compared to the stability of oxalic acid, renders it probable, that the secondary constituents of the two acids are very different.

3. Dr. Gobel has given us another analysis of this acid, by means of peroxide of copper. He analyzed formate of lead, and found it a compound of

Formic acid . .	4·5693
Protoxide of lead .	14·0744
Water . . .	1·1063
	19·75*

Doubtless the true numbers are

1 atom formic acid .	4·625
1 atom protoxide of lead	14·000
1 atom water . .	1·125
	19·75

He analyzed 10 grains of the formate of lead by heating it with peroxide of copper in a glass tube. His description of the result of the analysis is not very clear, and it seems to contain some arithmetical slips. When these are corrected (supposing the formate of lead used anhydrous) the constituents obtained were the following:

* Annals of Philosophy, (second series) III. 463.

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Hydrogen	.	0·0698	or	0·129
Carbon	.	0·7970	-	1·485
Oxygen	.	1·6164	-	3·011
		2·4832		4·625

In this analysis the hydrogen and oxygen are exceedingly near the truth. There is a slight deficit in the carbon, which, however, amounts only to 1 per cent.

4. The experiments of Dobereiner tend strongly to confirm the constitution of formic acid as determined by the preceding experiments. He found that, when concentrated sulphuric acid was mixed with formic acid, carbonic oxide gas was extricated; while the acid became weaker, from an addition of water. Now, it is obvious that, if formic acid be a compound of 1 atom hydrogen, 2 atoms carbon, and 3 atoms oxygen, it may be resolved into water and carbonic oxide; for,

	HYDROGEN.	OXYGEN.	CARBON.
1 atom water consists of	1 atom	+ 1 atom	+ 0 atom
2 atoms carbonic oxide of	0 -	+ 2 -	+ 2 -
	1	+ 3	+ 2

So that 4·625 grains of formic acid may be decomposed into 1·125 grain of water, and 3·5 grains of carbonic oxide, equivalent to 11·8 cubic inches of carbonic oxide gas.

5. Dobereiner has made another curious dis-

Formation of this acid from tartaric.

covery, which has put it in my power to obtain formic acid, and to ascertain its properties. He found that, when tartaric acid, or bitartrate of potash, is mixed with black oxide of manganese and water, and a gentle heat applied, an effervescence takes place, and carbonic acid gas is evolved, while a colourless acid liquid passes over into the receiver, which is formic acid. When sulphuric acid is added, the whole of the tartaric acid is decomposed, and a greater quantity of formic acid is obtained. During the process, the tritoxide of manganese is converted into protoxide, which combines with the sulphuric acid; or, if that acid be not present, with the tartaric and formic acids. The best proportions he finds to be

1 part of crystallized tartaric acid,
2½ parts tritoxide of manganese,
2½ parts of sulphuric acid, which should be diluted with twice or thrice its weight of water.*

If we compare the constituents of tartaric and formic acids, we will be enabled to see what takes place in this case.

	HYDROGEN.		CARBON.		OXYGEN.
Tartaric acid	2	+	4	+	4
Formic acid	1	+	2	+	3
	—		—		—
Difference	1	+	2	+	1

* Gilbert's Annalen, LXXI, 108.

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This difference is reducible to an atom of water and two atoms of carbon. The sulphuric acid seems to remove the atom of water, which destroys the equilibrium of the constituents of the acid. The two surplus atoms of carbon are converted into carbonic acid, by uniting with the oxygen of the tritoxide of manganese.

If we suppose all the substances employed in this experiment pure, it is evident that the atomic quantities requisite for the decomposition of the tartaric acid, and formation of formic acid, must be

1 atom tartaric acid . .	9·375
2 atoms tritoxide of manganese	11
2 atoms sulphuric acid .	12·25

Or, 24·75 of bitartrate of potash might be substituted with equal advantage, instead of the 9·375 of tartaric acid.

SECT. IX.

OF THE ATOMIC WEIGHT OF URIC ACID.

This acid was detected by Scheele, and some of its most characteristic properties determined. It was afterwards examined more in detail by Dr. Henry of Manchester, who made it the subject

of his inaugural dissertation. Since that time, some important additions have been made to our knowledge of its properties and constitution by Dr. Prout.

The uric acid which I made use of in the following experiments was obtained from the excrements of the boa constrictor. This serpent voided its excrements about once in the month: the matter was white and solid, and in appearance very similar to the album Græcum voided by dogs. A slight examination of it satisfied me that it consisted almost entirely of uric acid. It was digested in caustic potash ley, by which the greatest part of it (indeed almost the whole) was dissolved. The solution was drawn off clear from the undissolved sediment, and mixed with a sufficient quantity of very pure acetic acid, to saturate the whole of the potash. A copious white precipitate fell, which was collected on the filter, and thoroughly washed by the affusion of a great quantity of water. It was then dried in a gentle heat, and considered as pure uric acid.

Properties of uric acid.

1. Uric acid thus prepared was sometimes in the state of an impalpable powder—sometimes in small four-sided prisms, having a good deal of lustre. I was not able to procure these crystals at pleasure; but succeeded most frequently when the precipitate was separated by the filter from the supernatant liquid, immediately after

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being thrown down. When I allowed the precipitated acid to remain in the mother liquor for 24 hours, I never got it in any other state than an impalpable powder.

Uric acid is tasteless, very white, very light, and quite insoluble in water and alcohol.

In concentrated sulphuric acid it speedily assumes the form of a jelly; and, upon applying a very gentle heat, a complete solution is obtained, without in the least affecting the colour or transparency of the acid. In nitric acid, even though dilute, it dissolves with effervescence. The solution is nearly colourless, and when it is evaporated to dryness, it leaves a sediment having a beautiful pink colour; and if water be poured over it, a most lovely pink coloured solution is obtained—which, however, cannot be preserved for any length of time without entirely losing its colour. In muriatic acid it dissolves only in small proportion, the undissolved part assuming a fine white colour. If uric acid be precipitated with a tinge of buff or yellow, which sometimes happens, the easiest way of restoring the whiteness is to digest it in pure muriatic acid. When the muriatic acid is evaporated, it leaves a slight sediment upon the bottom of the vessel, which has a yellowish brown colour, and which is not altered by pouring water over it.

2. Uric acid may be united with the different bases by boiling it in water, holding the wished-

for base in solution. The urates of potash, soda, lime, barytes, and strontian, formed in this way, almost exactly resemble the uric acid itself in appearance. Dr. Prout has shown that urate of ammonia is the most soluble of all the urates. This salt reddens vegetable blues like uric acid itself; and 1 grain of it is soluble in 480 grains of cold water.

3. 11·25 grains of uric acid were exposed for 24 hours to a heat of about 400°, upon a sand bath: the acid was placed upon a watch glass, over which another watch glass was inverted, partly to prevent any accidental impurity, and partly to prevent any of the acid from being dissipated or sublimed without my knowledge. Some water was seen to attach itself to the upper glass, but in less than an hour all appearance of moisture had vanished, and no farther sensible alteration took place. The crystals, thus treated, being weighed, were found to have lost 2·25 grains of their weight,—the colour was rather darker than before this treatment, but no other alteration could be perceived in the appearance of the crystals. When treated with nitric acid, they exhibited the very same phenomena as uric acid which had not been exposed to heat. From this experiment it appears, that crystallized uric acid is composed of

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Real acid . . .	9
Water . . .	2·25
	11·25

As 2·25 represents 2 atoms of water, the probable inference from this experiment is, that the atomic weight of uric acid is 9, and that the crystals constitute a hydrate composed of

2 atoms water . .	2·25
1 atom uric acid . .	9
	11·25

Analysis of urate of soda.

4. 18 grains of crystallized carbonate of soda were dissolved in distilled water, and to the solution 11·25 grains of crystallized uric acid were added. This mixture being digested for some hours on the sand bath, the whole uric acid disappeared, and a complete colourless solution was obtained; which, however, still rendered cudbear paper violet. The solution being set aside, a bulky and beautifully white precipitate of urate of soda fell: this precipitate being separated on a double filter, well washed and dried in the open air, was found to weigh 8·56 grains; and, when exposed to a heat of between 300° and 400°, it lost very nearly 1·125 grains,—the residual liquid was supersaturated with muriatic acid and evaporated to dryness—the residual matter, which was white, with a shade of brown, weighed 6·94 grains. It was heated to redness, lixiviated

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with distilled water, and the water evaporated to dryness in a glass capsule; the common salt which remained behind weighed 2·94 grains, equivalent to 1·568 grains of soda.

In order to understand the preceding experiment, it is necessary to know that the crystals of carbonate of soda are composed of

1 atom carbonic acid .	2·75
1 atom soda . .	4
10 atoms water . .	11·25
	18

So that 18 grains of this salt are equivalent to 4 grains of soda. Let us now analyze the preceding experiment.

(1.) We see from it that uric acid (contrary to the present opinion of chemists) is capable, in time, of driving off the whole of the carbonic acid from carbonate of soda, and taking the place of that acid. No effervescence took place when the muriatic acid was poured into the residual liquid from which the urate of soda had precipitated—a proof that the whole soda had united to the uric acid. It appears from this, that urate of soda, while in solution, has the property of giving a violet colour to cudbear paper, so that the acid does not destroy the alkaline qualities of the soda.

(2.) The urate of soda which remained in solution must have consisted of

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Uric acid . . .	4
Soda . . .	1·568
	5·568

For, if we subtract the weight of the common salt (2·94 grains) from that of the residual matter, (6·94 grains) there remain 4, which must be uric acid; and 2·94 grains of common salt are equivalent to 1·568 grains of soda.

(3.) The 8·56 grains of urate of soda obtained by precipitation, obviously contained 2·432 grains of soda. When heated, this salt lost 0·656 grain of its weight, which was water, for it condensed on the glass placed over the evaporating capsule. Hence, it is obvious that the urate of soda was composed of

Uric acid . . .	5·472
Soda . . .	2·432
Water . . .	0·656
	8·560

Let us reduce this to what the weight of each ingredient would be if the soda had amounted to 4 grains, which is equivalent to an atom of that alkali, and we have the constitution of urate of soda as follows:

Uric acid . . .	9
Soda . . .	4
Water . . .	1·079

9 must denote the atomic weight of uric acid—1·079 is a very little less than an atom of water. There can be no doubt, from this analysis, that the true composition of urate of soda, supposing it to retain all its water of crystallization, is as follows:

1 atom uric acid	. .	9
1 atom soda	. .	4
1 atom water	. .	1·125
		14·125

Composition of uric acid.

5. Dr. Prout made a very careful analysis of uric acid, by exposing the acid in the state of hydrate to heat, mixed with the requisite quantity of peroxide of copper. He found the constituents as follows:

2 atoms hydrogen	. .	= 0·25
6 atoms carbon	. .	= 4·5
2 atoms azote	. .	= 3·5
3 atoms oxygen	. .	= 3·0
		11·25

The weight of the hydrate, according to this analysis, is 11·25—just what I found it to be in the preceding experiments. But we have seen that this hydrate contains 2 atoms water, and that the true atomic weight of the anhydrous acid is 9. To obtain the true constitution of the anhydrous acid, we must take away from the

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preceding constituents 2 atoms hydrogen and 2 atoms oxygen; this will give us the component parts of uric acid as follows:

6 atoms carbon	. .	= 4·5
2 atoms azote	. .	= 3·5
1 atom oxygen	. .	= 1·0
		9

Thus, uric acid, when anhydrous, contrary to the opinions hitherto entertained by chemists, contains no hydrogen, and instead of a quaternary is only a ternary compound, like the vegetable acids. It contains a much smaller proportion of oxygen than any of the vegetable acids.

CHAP. XV.

OF THE ATOMIC WEIGHT OF FLUORIC ACID AND ITS COMPOUNDS.

The investigation of the atomic weight of fluoric acid is attended with particular difficulties, owing to the great tendency which it has to combine with silica. The fluor spar employed for procuring it is seldom quite free from silica; but the specimens selected, in order to procure the acid for investigation, must be quite pure. The spar must be reduced to powder, mixed with sulphuric acid, and heated in metallic vessels, and the fluoric acid must be received in a metallic vessel; for if the acid come in contact with glass it is instantly converted into fluosilicic acid. I employed a leaden alembic and receiver for preparing the acid; but I find that it cannot be kept in a leaden vessel for any length of time, for the lead is soon corroded, and an insoluble fluate of lead formed. Vessels of silver answer very well for keeping it, provided the stopper be air tight; for it is so volatile as not to be easily confined. I put a vessel containing it upon a shelf in a press, where I keep my collection of acids in glass phials; on opening the press door some days after, I was surprised to observe all the phials quite opaque,

and white on the outside, as if they had been coated over with silica. The fluoric acid had made its escape, and had corroded the whole of the surface of every one of the phials.

SECT. I.

OF THE ATOMIC WEIGHT OF FLUORIC ACID.

THE properties of pure fluoric acid have been detailed with great accuracy by Gay-Lussac and Thenard, and by Sir H. Davy. I have nothing to add to the statements of these eminent chemists, except to say that I found them all quite exact so far as I repeated them.

1. The only person who has attempted to determine the atomic weight of fluoric acid, so far as I know, is Berzelius. And it will be worth while, before I detail the experiments which I have myself made, to state those of this most laborious and accurate experimenter. He endeavoured to determine the atomic weight of this acid by analyzing fluate of silver, fluate of barytes, and fluate of lime, each in as pure a state as he could prepare them.

Berzelius' experiments to determine the atom of fluoric acid.

(1.) 4·936 parts of fused fluate of silver left, when dissolved in water, 0·185 of metallic silver —so that the quantity of fluate of silver actually dissolved was 4·751 parts. This solution being precipitated by sal-ammoniac, furnished 5·349

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parts of fused chloride of silver, which is equivalent to 4·32316 parts of oxide of silver. Consequently, if the fluate of silver was anhydrous, and composed of fluoric acid and oxide of silver, its constituents must be

Fluoric acid	0·42784	or	1·45965
Oxide of silver	4·32316	-	14·75
	4·75100 *		

(2.) Six parts of fluate of barytes, when decomposed by sulphuric acid, yielded 7·968 parts of sulphate of barytes, equivalent to 5·267 parts of sulphate of barytes. Hence, fluate of barytes is composed of

Fluoric acid	0·733	or	1·35693
Barytes	5·267	-	9·75
	6·000 †		

(3.) Ten parts of very pure transparent fluate of lime from Derbyshire, when decomposed by sulphuric acid, furnished 17·368 parts of sulphate of lime, equivalent to 7·15153 parts of lime. Hence, fluate of lime is composed of

Fluoric acid	2·84847	or	1·39446
Lime	7·15153	-	3·5
	10·00000		

(4.) Sir H. Davy had made a previous analysis of fluor spar which deserves to be stated. He found its constituents

* Annals of Philosophy, XV. 279. † Ibid.

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Fluoric acid	27·859	or	1·3514
Lime	72·141	-	3·5
	100·000		

The second column of figures exhibits the atomic weight of fluoric acid, according to these experiments. The reader will perceive that the analysis cannot be perfectly accurate, because a different atomic weight is obtained from every salt examined.

From fluate of silver it is . . .	1·45965
From Berzelius' analysis of fluor spar it is	1·39446
From fluate of barytes it is . . .	1·35693
From Davy's analysis of fluor spar it is	1·3514

The highest atomic weight is 1·45965 and the lowest 1·3514.

Experiments of the author.

2. I prepared some very pure fluate of soda by the following process: Two ounces of carbonate of ammonia were dissolved in water, and a current of fluosilicic acid gas was passed through the liquid till the ammonia was saturated. The solution was then filtered into a silver bason, and carbonate of soda added by small quantities at a time, till the ammonia was almost all driven off, and fluate of soda formed. The whole was then evaporated to dryness in a silver bason, and the dry salt redissolved in water and filtered again, to get rid of a little silica which it still contained. The clear liquid was

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evaporated in a silver crucible till the fluate of soda crystallized. It formed transparent crusts very like ice, having a saline but not a strong taste; it was heated in a silver crucible till its water of crystallization was expelled. In this state it formed opaque white crusts, which became again transparent when put into water. The salt had been prepared with so much care, that there was no reason to doubt of its purity. In order to be sure that it was quite anhydrous, the crucible containing it was raised to a low red heat before every experiment.

(1.) 5·25 grains of this salt (which was neutral) were dissolved in a little water in a platinum crucible.

Into another platinum crucible were put 6·25 grains of pure calcareous spar, (equivalent to 3·5 grains of lime,) which were dissolved in dilute muriatic acid; the solution evaporated to dryness, and the salt which was left was dissolved in water.

These two liquids being mixed together, a double decomposition took place, fluate of lime being deposited, and muriate of soda remaining in solution. The crucible containing the whole contents was put on the sand bath, and the whole liquid evaporated to dryness by means of a very gentle but long continued heat. A little hot distilled water was then poured on the dry saline mass, and allowed to remain digesting on

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it in a very moderate heat for twenty-four hours. A little of the water was then drawn off, and tested with oxalate of ammonia and muriate of lime. It did not become in the least muddy or even opalescent, showing that it contained no sensible quantity either of lime or fluoric acid.

The fluate of lime, formed in this experiment, was carefully collected on a double filter, washed and dried, first in the open air, and then heated to redness. Its weight certainly did not differ by $\frac{1}{100}$th of a grain from 4·75 grains.

From this experiment, which was repeated four or five times before I succeeded in removing all ambiguity from the phenomena, it is evident that 5·25 grains of anhydrous fluate of soda contain just the quantity of acid necessary to saturate 3·5 grains of lime; and that the fluate thus formed weighs 4·75 grains. Hence, it must consist of

Composition of fluate of lime.

Fluoric acid	1·25
Lime	3·5
	4·75

3·5 being the atomic weight of lime, and the salt being neutral, it is obvious that 1·25 must denote the weight of an atom of fluoric acid. It is obvious, likewise, that the anhydrous fluate of soda was composed of

Atom of fluoric acid.

Fluoric acid	1·25
Soda	4
	5·25

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for it was neutral, and contained (as we have seen) 1·25 of fluoric acid, which, being equivalent to an atom, required for saturation 4, or an atom of soda.

(2.) 5·25 grains of anhydrous fluate of soda, and 13·25 grains of chloride of barium were dissolved in separate portions of water, the liquids were mixed together, and evaporated to dryness in a platinum crucible by means of a very gentle heat. Distilled water was poured upon the residue, and digested on it for twenty-four hours. A little of it was then drawn off, and tested with sulphate of soda and muriate of barytes; but it was not in the least affected by either of these reagents, showing that it contained no sensible quantity either of barytes or of fluoric acid.

Fluate of barytes.

The fluate of barytes formed in this experiment, being collected on a double filter, washed, dried, and heated to redness, weighed almost exactly 11 grains.

This experiment agrees with the preceding, and serves to confirm it. We see that anhydrous fluate of barytes is composed of

Fluoric acid	1·25
Barytes	9·75
	11

and that 1·25 grains of fluoric acid just saturate 9·75 grains of barytes. This experiment, like the preceding, was made four or five times be-

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fore I thought of evaporating the whole liquid to dryness. I found traces both of fluoric acid and of barytes in the liquid, whatever proportion of the two salts I mixed; it was the same thing with the fluate of lime. To expel these two salts completely, we must evaporate the liquids containing them to dryness. Then they become insoluble, and we can easily determine by means of a little water whether any of the fluate of soda, and of the muriate of lime, or muriate of barytes originally employed, still exist in the dry salt formed.

Fluate of lead.

(3.) I tried whether solutions of 5·25 grains of fluate of soda, and 20·75 grains of nitrate of lead would completely decompose each other, but the experiments, though frequently repeated, led to no satisfactory results; for I could detect both fluoric acid and oxide of lead in the residual liquid, whether I employed the salts in these proportions, or increased or diminished the quantity of fluate of soda. I was not at that time aware of the effect produced by evaporating the mixture to dryness, and after I became aware of it, my stock of fluate of soda was too far exhausted to allow me to resume my experiments with nitrate of lead, without the risk of not leaving enough to determine the atomic weight of fluoric acid exactly, by means of muriate of lime and muriate of barytes, which I considered as of most importance.

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(4.) These experiments show decidedly that the atomic weight of fluoric acid is 1·25. It is obvious, therefore, that the true constituents of fluate of barytes are

Fluoric acid	0·6818
Barytes	5·3182
	6·0000

instead of

Fluoric acid	0·733
Barytes	5·267
	6·000

the proportions found by Berzelius, owing probably to a little silica existing in his fluate of barytes.

It is equally obvious, that the true composition of fluate of lime is

Fluoric acid	26·3158
Lime	73·6842
	100·0000

which approaches nearest to the analysis of Sir H. Davy. I made some experiments with fluor spar in the same way as Berzelius; but they did not agree with each other so closely as to induce me to put much confidence in their accuracy. Indeed, unless we were assured before hand of the perfect purity of the fluor spar employed,

the analysis of it could not lead to any useful result.

SECT. II.

OF THE ATOMIC WEIGHT OF FLUOSILICIC ACID.

When sulphuric acid is poured upon the powder of fluor spar in a glass retort, or upon a mixture of pounded glass and fluor spar, and heat applied, it is well known that a gas is extricated, which was long distinguished by the name of fluoric acid; but the presence of silica, which had been recognised in it from the first, has induced modern chemists to give it the name of fluosilicic acid. For by far the most accurate set of experiments on this gas we are indebted to Dr. Davy.*

Specific gravity.

The specific gravity of this gas, as determined by Dr. Davy, is 3·5735. I found the specific gravity 3·58313; but the specimen examined contained a very small proportion of common air. The quantity of this mixture being ascertained and deducted, I found that the real specific gravity was 3·6; for reasons which will appear immediately, I consider the true specific gravity of this gas to be 3·6111, that of air being reckoned unity. Consequently, 100 cubic inches

* Phil. Trans. 1812. p. 352.

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of it at the temperature of 60°, and when the barometer stands at 30 inches, weigh 110·1385 grains.

When this gas is placed in contact with liquid ammonia it is rapidly absorbed, while the silica which it contains is deposited in a gelatinous state. Dr. Davy found that 40 cubic inches of the gas, when thus treated, deposited 27·2 grains of silica. Upon repeating the experiment, I obtained 27·1 grains of silica; but having procured an apparatus by which I could measure the volume of the gas to within $\frac{1}{1000}$th of a cubic inch, the weight of the silica obtained from 40 cubic inches of the gas was 27·14 grains, or more nearly 27·145 grains.* Now, the weight of 40 cubic inches of this gas is 44·0554 grains. Consequently, it appears from this experiment, that fluosilicic acid is a compound of

Composition of fluosilicic acid.

Fluoric acid	16·9104	or	1·25
Silica	27·1450	-	2·006
	44·0554		

1·25 is the atomic weight of fluoric acid, and

* This experiment is of very difficult execution, and cost me much labour and time before I was able to execute it with the requisite precision. The silica is very bulky and light, and is apt to be dissolved by the water employed to wash it. In consequence of this, I obtained always too little silica at first, till I discovered the source of the diminution. I have omitted all the unsuccessful experiments. Those given in the text I consider as very near the truth

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2·006 approaches so nearly to 2, the atomic weight of silica, that we can have no hesitation in considering fluosilicic acid as a compound of 1 atom fluoric acid and 1 atom silica; hence, its atomic weight is 3·25.

It was shown in the seventh chapter of this work, that if we multiply the atomic weight of a gaseous body by 1·111$\dot{1}$ (the specific gravity of oxygen gas) or 0·555$\dot{5}$, (half the specific gravity of oxygen gas) or by 0·277$\dot{7}$ ($\frac{1}{4}$th of that specific gravity) we obtain the specific gravity of the gaseous body so multiplied. Now, 3·25 × 1·111$\dot{1}$ = 3·611$\dot{1}$. This number approaches so nearly the specific gravity of fluosilicic acid determined experimentally, as to leave no doubt that it represents the true specific gravity of this gas.

The specific gravity of fluosilicic acid gas, then, is 3·611$\dot{1}$, and its atomic weight 3·25, and it is a compound of 1 atom fluoric acid and 1 atom silica.

As this gas is decomposed when it comes in contact with water, there are very few of its saline combinations which we have it in our power to form; for the dry bases, as far as my trials went, did not exhibit any disposition to absorb it. When one volume of fluosilicic acid gas is mixed with two volumes of ammoniacal gas, they condense each other into a white solid salt, which is obviously a fluosilicate of ammonia.

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This salt is a white powder, which has a saline taste, pretty similar to that of sal-ammoniac. When laid dry upon litmus paper it does not produce any alteration, but when a drop of water is added, the litmus paper becomes red. Fluosilicate of ammonia dissolves in water; but flocks of silica are at the same time disengaged, and the solution reddens vegetable blues. Hence, it is obvious, that water has the property of destroying this salt by decomposing its acid.

From the account given of fluosilicic acid in the preceding part of this section, it is obvious, that it resembles oxygen gas in the number of atoms contained in a given volume of the gas; but oxygen gas contains four times as many atoms in a given volume, as ammoniacal gas does. It follows from this, that the fluosilicate of ammonia, formed by mixing the two gases, is a compound of 2 atoms fluosilicic acid, and 1 atom of ammonia; or it is a bifluosilicate of ammonia. Hence, its composition and atomic weight must be as follows:

2 atoms of fluosilicic acid	6·5
1 atom ammonia	2·125
	8·625

It is obviously anhydrous.—I did not find that one volume of fluosilicic gas was capable of condensing four volumes of ammoniacal gas. I

succeeded once in obtaining a complete condensation by mixing three volumes of the acid gas with four volumes of the alkaline gas; but a repetition of the experiment did not succeed.

SECT. III.

OF THE ATOMIC WEIGHT OF FLUOBORIC ACID.

Messrs. Gay-Lussac and Thenard discovered another compound gas, one of the ingredients of which is fluoric acid, and the other boracic acid. It has been generally distinguished by the name of *fluoboric acid*. They procured it by exposing a mixture of fluor spar and anhydrous boracic acid to a strong heat. The gas came over in abundance, and was collected over mercury. Dr. Davy, to whom we are indebted for an excellent set of experiments on this gas, procured it by mixing together one part of anhydrous boracic acid and two parts of fluor spar in a retort, and pouring twelve parts of sulphuric acid on the powder. When the heat of a lamp is applied, the gas comes over, and it must be received over mercury. I prepared the gas by Dr. Davy's method, not having been provided with an apparatus similar to that employed by the French chemists; but I found the process

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very tedious, and the quantity of gas obtained but small.

The specific gravity of this gas was found by Dr. Davy to be 2·3709. I took its specific gravity two different times with great care, and obtained 2·3984. This, as will appear immediately, exceeds the theoretical specific gravity by a quantity rather too great to be ascribed to error in experimenting. I was long unable to account for this difference; I could perceive no mistake in the process, and a repetition of it gave me almost exactly the same result. I found that the gas contained a slight mixture of fluosilicic acid gas. The volume of this being determined, and allowed for, reduced the specific gravity of fluoboric acid gas to 2·38833, which is still above the theoretical gravity. At last I discovered that this gas carries along with it a little sulphuric acid, which, of course, increases its gravity somewhat. According to the most accurate experiments which I could make, 100 cubic inches of the fluoboric acid gas which I examined, contained about 0·8 grain of sulphuric acid. Now, if from 72·844 grains, which I found to be the weight of 100 cubic inches of this gas, we subtract 0·8, there will remain 72·044 grains for the true weight of fluoboric acid gas. This will make its specific gravity 2·3622. Now, we shall see immediately, that the theoretical specific gravity, which undoubtedly must be ex-

Specific gravity.

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act, is 2·3611—a number which comes within $\frac{1}{2000}$th part of the actual result of experiment—a difference considerably within the unavoidable errors of experiment.

Fluoborate of ammonia.

2. Dr. Davy found that fluoboric acid gas, and ammoniacal gas, combined with each other in the three following proportions:

(1.) 1 volume fluoboric gas, 1 volume ammoniacal gas } forming a solid salt.

(2.) 1 volume fluoboric gas, 2 volumes ammoniacal gas } forming a liquid.

(3.) 1 volume fluoboric gas, 3 volumes ammoniacal gas } forming a liquid.

Upon repeating these experiments I obtained the very same results.

From what was said in the seventh chapter of this treatise, it will be evident to the reader, that ammoniacal gas is twice as bulky with relation to its atomic weight as any of the other gases, with the exception of the four contained in the same table with it. Consequently, if we consider a volume of fluoboric acid gas to represent an atom, it is clear that an atom of ammonia must be represented by two volumes of that gas. It is, therefore, the second of the compounds of the two gases, consisting of 1 volume fluoboric gas, and 2 volumes ammoniacal

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gas, that represents the neutral compound of 1 atom of each constituent.

Now,

1 volume fluoboric gas weighs	2·3611	or	4·25
2 volumes ammoniacal .	1·1805	-	2·125

2·125 represents the weight of an atom of ammonia, and 4·25 must represent the weight of an atom of fluoboric acid. Now, an atom of boracic acid being 3, and an atom of fluoric acid 1·25, it is evident that fluoboric acid is a compound of 1 atom of boracic acid and 1 atom of fluoric acid united together. For

Atom of fluoboric acid.

$3 \times 1{\cdot}25 = 4{\cdot}25$ = the atomic weight of fluoboric acid.

The solid salt, composed of 1 volume fluoboric acid and 1 volume ammoniacal gas, is obviously a bifluoborate of ammonia, composed of

2 atoms fluoboric acid	8·5
1 atom ammonia .	2·125
	10·625

So that an integrant particle of it is represented by the number 10·625.

The third saline compound, consisting of 1 volume of fluoboric gas and 3 volumes of ammoniacal gas, is obviously a subsesquifluoborate, composed of

1 atom fluoboric acid	4·25
1½ atom ammonia	3·1875
	7·4375

So that an integrant particle of it weighs 7·4375.

The property which the neutral fluoborate of ammonia has to lose half of its ammonia when exposed to the air, and of being converted into a bisalt, is analogous to what happens to other ammoniacal salts. Thus when neutral carbonate of ammonia is exposed to the air in powder, one-half of the ammonia flies off, and a bicarbonate of ammonia remains.

It was shown in the seventh chapter of this treatise, that we obtain the specific gravity of most gases if we multiply their atomic weight by 0·5555̇ (= half the specific gravity of oxygen gas). This law holds in the present case. For

$$4{\cdot}25 \times 0{\cdot}5555\dot{} = 2{\cdot}3611\dot{},$$

a number which only differs by $\frac{1}{2000}$th part from the specific gravity obtained by experiment. This coincidence is too near to leave any doubt that 2·3611̇ is the true specific gravity of fluoboric acid gas.

In this chapter I have taken no notice of the hypothesis originally started by M. Ampere, and so ably supported by Sir H. Davy, that fluoric acid is a compound of equal volumes of hydro-

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gen gas and an unknown supporter of combustion, to which Davy has given the name of *fluorine*. All the facts stated above may be explained just as well by this hypothesis as by the common one. An atom of fluorine will weigh 2·25, and fluoric acid will be a compound of Fluorine.

1 atom fluorine	2·250
1 atom hydrogen	0·125
	2·375

Fluosilicic acid will be a compound of

1 atom fluorine	2·25
1 atom silicon	1
	3·25

And fluoboric acid will be composed of

1 atom fluorine	2·25
2 atoms boron	2
	4·25

Fluor spar will be a compound of

1 atom fluorine	2·25
1 atom calcium	2·5
	4·75

And in the same easy way may all the other combinations given in this chapter be represented according to Davy's theory. At the same time, this mode of representing these combinations does not give us any superior advan-

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tages in accounting for the phenomena. And as no satisfactory evidence of the existence of fluorine had been adduced, I think it safer in the present state of the subject, to abide by the old opinion, without pretending even to conjecture which of the two opinions will be ultimately established. Whoever can succeed in extracting from fluoric acid either a new combustible body, or a new supporter, will settle the point. But the difficulty of experimenting upon fluoric acid is so great, in consequence of the property which it has of decomposing glass vessels, that I was heartily tired of it by the time that I had made out its atomic weight and that of its two compounds, which was the object that I had in view.

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CHAP. XVI.

OF THE SULPHURETS.

In the preceding chapters, the composition of several of the metallic sulphurets has been noticed, but it may be acceptable to the reader to take a general view of this important class of bodies. This will be the subject of the present chapter.

1. Sulphuret of potassium. Gay-Lussac first showed that when sulphur and potash are heated together, a portion of the sulphur is acidified at the expense of the oxygen of the potash, and that the compound formed is a mixture of sulphate of potash and sulphuret of potassium.* This view of the matter was further confirmed by Vauquelin.† But for by far the most important set of experiments on the subject, we are indebted to Berzelius, whose paper on the Alkaline Sulphurets, published in 1821,‡ threw a new and unexpected light over this department of chemistry. Sulphurets of potassium,

Berzelius put a quantity of sulphate of potash into a glass tube, and after having heated it to

* Ann. de Chim. LXXVIII. 86. † Ann. de Chim. et de Phys. VI. 5.
‡ Kong. Vetensk. Acad. Hand. 1821. p. 80.

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redness, he passed a current of hydrogen gas over it as long as water continued to be formed. By this process, both the acid and base were deprived of their oxygen, and there remained a sulphuret of potassium composed of

1 atom sulphur	2
1 atom potassium	5
	7

It had a deep red colour, fused at a temperature below redness, and dissolved in water forming a coloured solution.

By substituting sulphuretted hydrogen gas instead of hydrogen, and repeating the process in the same way, he obtained a compound of

Potassium	5
Sulphur	7·21

5 is an atom of potassium, and 7·21 is somewhat less than 4 atoms of sulphur.

When the experiment was repeated, substituting bisulphuret of carbon, the sulphuret was composed of

Potassium	5
Sulphur	8·42

These compounds are not quite definite.

By fusing carbonate of potash and sulphur together in various proportions, Berzelius obtained several other compounds of potassium and sul-

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phur. The five following sulphurets of potassium seem to be established by these experiments.

	POTASSIUM.		SULPHUR.
1. Sulphuret of potassium	1 atom	+	1 atom
2. Bisulphuret . .	1 atom	+	2 atoms
3. Trisulphuret . .	1 atom	+	3 atoms
4. Quadrosulphuret .	1 atom	+	4 atoms
5. Quintosulphuret .	1 atom	+	5 atoms

Berzelius is also of opinion that there exist two others composed of

	POTASSIUM.		SULPHUR.
1.	1 atom	+	$3\frac{1}{2}$ atoms
2.	1 atom	+	$4\frac{1}{2}$ atoms

But though he formed substances containing the ingredients nearly in these proportions, it is more likely that they were mixtures. For we do not in other cases find sulphur entering into combination in such extraordinary proportions.

2. Sulphurets of sodium.
3. Sulphurets of lithium. } Though these sulphurets have not been particularly examined, we may conclude, from analogy, that they are similar to those of potassium. The protosulphuret of sodium was made by Berthier, and found very similar to the protosulphuret of potassium.*

4. Sulphuret of calcium was formed by Berzelius, by passing a current of sulphuretted hy- Calcium,

* Ann. de Chim. et de Phys. XXII. 225.

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drogen gas over red hot lime: water was formed, and the reduced calcium united with the sulphur of the gas. The sulphuret, thus obtained, was composed of

Calcium . . .	2·5
Sulphur . . .	1·988

Hence, it is obviously a protosulphuret composed of

1 atom calcium . .	2·5
1 atom sulphur . .	2
	4·5

Berthier formed it by heating anhydrous sulphate of lime in a charcoal crucible: the sulphuret of calcium obtained was white, dissolved completely in water, and was not altered by roasting. Its constituents were

Calcium . . .	2·5
Sulphur . . .	1·91

It was, therefore, a protosulphuret of calcium, like that obtained by Berzelius.

Barium, 5. Sulphuret of barium was formed by Berthier from sulphate of barytes, precisely in the same way as he had obtained sulphuret of calcium. This sulphuret is white, with grey spots slightly cohering, capable of being kneaded between the fingers, and in crystalline grains. It dissolved completely in water, and the solution

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was colourless. Muriatic acid disengaged sulphuretted hydrogen from the solution. The sulphuret of barium is not altered by roasting, but when detonated with nitre it is converted into sulphate of barytes.* Hence, it is obviously a protosulphuret of barium composed of

1 atom barium . .	8·75
1 atom sulphur . .	2
	10·75

In Berthier's process there was a slight loss of the sulphur. Hence, he obtained a compound of

Barium . . .	8·75
Sulphur . . .	1·95

6. Sulphuret of strontium. This sulphuret was obtained by Berthier in a similar way; its properties agree nearly with those of sulphuret of calcium. It was a protosulphuret composed of Strontium,

1 atom strontium . .	5·5
1 atom sulphur . .	2
	7·5

In Berthier's process a little of the sulphur had escaped, for he obtained a compound of

Strontium . . .	5·5
Sulphur . . .	1 95

* Ann. de Chim. et de Phys. XXII. 232.

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7. Sulphuret of magnesium is not so easily obtained as the sulphurets of the preceding metals. When sulphate of magnesia is heated in charcoal almost the whole acid is dissipated, and nothing remains but magnesia mixed with a small quantity of sulphuret of magnesium. But sulphuret of magnesium may be obtained in combination with sulphuret of potassium, by heating a mixture of sulphates of potash and magnesia in charcoal: Berthier has shown that it is a protosulphuret of magnesium which is thus obtained. It is a compound of

1 atom magnesium . .	1·5
1 atom sulphur . .	2
	3·5

There was an excess of sulphur in the sulphuret formed by Berthier, amounting to rather less than ¼th of an atom.

8. No attempts have been hitherto made to form the sulphurets of aluminum, glucinum, yttrium, or zirconium. It is by no means unlikely that some of the processes tried by Berzelius would succeed in forming these sulphurets also.

Iron, 9. Sulphuret of iron. Iron and sulphur combine in three proportions.

(1.) The protosulphuret may be formed by heating a mixture of iron filings and sulphur in a close crucible, and continuing the heat till the ex-

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cess of sulphur is driven off. It has a pale yellow colour, and I have sometimes obtained it in small crystals—it is attracted by the magnet. This sulphuret may be obtained, likewise, by mixing a solution of protosulphate of iron with hydrosulphuret of potash: a black precipitate falls, which is a protosulphuret of iron. Its constituents are

1 atom iron . . .	3·5
1 atom sulphur . .	2
	5·5

(2.) The sesquisulphuret of iron is obtained when a solution of neutral persulphate of iron is precipitated by hydrosulphuret of potash,—it is necessary to drop the iron solution into the hydrosulphuret: if we reverse the process, the powder which falls is a protosulphuret of iron. The sesquisulphuret of iron is a black powder, which has not been much examined. Its constituents are

1 atom iron . .	3·5
1½ atom sulphur . .	3
	6·5

(3.) Persulphuret of iron is found native, and is known by the name of iron pyrites. It is a brass yellow substance, having the metallic lustre, and usually crystallized in cubes, either smooth or striated—it is not the least attracted

by the magnet. This sulphuret may be obtained also artificially, by mixing intimately together 2 parts of protosulphuret of iron and 1 part of sulphur, and heating it in a temperature which must never be elevated to redness. When persulphuret of iron is heated to redness in close vessels, one half of the sulphur is sublimed and protosulphuret of iron remains. It is a compound of

1 atom iron . . .	3·5
2 atoms sulphur . .	4
	7·5

Berthier has shown, that protosulphuret of iron is formed when protosulphate of iron is heated in a charcoal crucible.

When magnetic pyrites is dissolved in an acid some sulphur precipitates: hence, it obviously contains either a slight excess of sulphur, or a slight mixture of cubic pyrites; for protosulphuret of iron dissolves in acids without any deposite of sulphur.

Nickel. 10. Sulphuret of nickel. It may be formed by fusing a mixture of oxide of nickel and sulphur in close vessels, and continuing the heat till the excess of sulphur is driven off. This sulphuret occurs in the mineral kingdom, and was formerly distinguished by the name of *Haarkies (hair pyrites)*. When a current of

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sulphuretted hydrogen gas is passed through a neutral solution of nickel in an acid, the sulphuret of nickel also precipitates; but the precipitation is prevented by adding an excess of acid to the solution. The colour of the sulphuret is yellowish grey; it has the metallic lustre, and is not brittle; it is not attracted by the magnet. Its constituents are

1 atom nickel . .	3·25
1 atom sulphur . .	2
	5·25

11. Sulphuret of cobalt. This sulphuret may be formed either by heating metallic cobalt or its oxide with sulphur in close vessels. It precipitates when sulphuretted hydrogen gas is passed through a solution of cobalt, provided there be no excess of acid, which prevents the precipitate from appearing. This sulphuret has a greyish yellow colour, a metallic lustre, and appears crystallized; it melts in a red heat. Its constituents are Cobalt,

1 atom cobalt . .	3·25
1 atom sulphur . .	2
	5·25

12. Sulphuret of manganese. This sulphuret is easily obtained by heating the protosulphate of manganese in a charcoal crucible. Prepared in this way, it has an iron grey colour, a semime- Manganese,

tallic lustre, and a crystalline appearance. Its avidity for oxygen is so great that when put into nitric acid it decomposes both the acid and the liquid. When protacetate of manganese is precipitated by an alkaline hydrosulphuret, or by a current of sulphuretted hydrogen gas, a yellowish precipitate falls, which becomes red when collected on the filter, and at last white; when heated, it gives out water and becomes green. It is uncertain, at present, whether this precipitate be a hydrosulphuret of manganese, or a hydrated sulphuret; but what remains after the powder is exposed to heat is a sulphuret of manganese.

Sulphuret of manganese is found native at Nagyag, in Transylvania, and has been described by the German mineralogists under the name of *Manganblende*. It was considered, from the analyses of Klaproth and Vauquelin, as a compound of protoxide of manganese and sulphur; but modern chemists have ascertained that it is in reality a sulphuret of manganese. It has a steel grey colour, and occurs crystallized in oblique four-sided prisms; the fracture is foliated, and the specific gravity 3·950. The constituents of sulphuret of manganese are

1 atom manganese .	3·5
1 atom sulphur . .	2
	5·5

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for it dissolves in acids without the deposition of any sulphur.

13. Sulphuret of cerium. This sulphuret is still unknown. When a solution of cerium is precipitated by a hydrosulphuret, the precipitate is in the state of an oxide, and the sulphuretted hydrogen gas escapes. When sulphur is heated with peroxide of cerium, protosulphate of cerium is formed, and perhaps some sulphuret. The mass has a green colour. Cerium,

14. Sulphuret of zinc. When a solution of sulphate of zinc is precipitated by hydrosulphuret of potash, the precipitate is white; but when heated, it becomes light yellow. In this state it is a sulphuret of zinc, similar in its composition to yellow blende. Berthier has shown that this sulphuret is formed likewise when sulphate of zinc is heated in a charcoal crucible. He found that charcoal, in a high temperature, has the property of decomposing blende—bisulphuret of carbon is formed, and zinc sublimes. Sulphuret of zinc dissolves in acids, without depositing any sulphur. It is, therefore, a compound of Zinc,

1 atom zinc . .	4·25
1 atom sulphur .	2
	6·25

15. Sulphuret of cadmium. This sulphuret is formed when cadmium and sulphur are heated Cadmium,

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together, or when a salt of cadmium is precipitated by sulphuretted hydrogen—the sulphuret has a fine yellow colour. In a white heat it melts, and crystallizes in cooling; and the crystals are a fine lemon yellow. It dissolves in muriatic acid, without depositing any sulphur, but with the evolution of sulphuretted hydrogen gas. Hence, its constituents are

1 atom cadmium .	7
1 atom sulphur .	2
	9

Tin, 16. Sulphuret of tin. Three sulphurets of tin are known.

(1.) Protosulphuret of tin is obtained when sulphur and tin are heated together in a close vessel. To saturate the tin with sulphur, the process should be repeated a second time, mixing the sulphuret intimately with a new portion of sulphur, and exposing the mixture to a full red heat, to drive off all excess. The sulphuret thus formed has the metallic lustre, a bluish grey colour, and fibrous and crystalline appearance. It dissolves in concentrated muriatic acid, without depositing any sulphur; and the gas extricated is totally absorbed by caustic potash. Hence the constituents of this sulphuret are

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1 atom tin . .	7·25
1 atom sulphur .	2
	9·25

(2.) If protosulphuret of tin be reduced to a fine powder, triturated with the third of its weight of sulphur, and the mixture be distilled in a heat raised very nearly to redness, till no more sulphur passes off, the sulphuret increases in weight about ten and a half per cent., or, more exactly, 9·25 of protosulphuret became 10·25. It is obvious from this, that a sesquisulphuret of tin has been formed, composed of

1 atom tin . .	7·25
1½ atom sulphur .	3
	10·25

This sulphuret has a yellowish colour, the metallic lustre, and takes a fine polish when rubbed upon a hard body.

(3.) Persulphuret of tin may be obtained by precipitating permuriate of tin by means of sulphuretted hydrogen. The well known substance called Mosaic gold, which is in beautiful yellow scales, and which is prepared in the dry way, by a process pointed out by Mr. Woulfe, is a persulphuret of tin. Its constituents are

1 atom tin . .	7·25
2 atoms sulphur .	4
	11·25

Lead. 17. Sulphuret of lead. There are two sulphurets of lead, both of which I have met with native.

(1.) Protosulphuret of lead is common galena, a well known ore of lead. It has a bluish white colour, the metallic lustre, is crystallized in cubes, very heavy, and very brittle; it melts easily when heated, but does not part with any of its sulphur. Its constituents are

1 atom lead . .	13
1 atom sulphur .	2
	15

(2.) About 20 years ago, I got a specimen of galena from Sir John Sinclair, which had the property of burning with a blue flame when held to the flame of a candle. When distilled, it gave out a quantity of sulphur. I did not subject it to analysis; but, from these properties, it was obviously either a sesquisulphuret or bisulphuret of lead.

(3.) Berthier has shown that, when sulphate of lead is exposed to a strong heat in a charcoal crucible, it is converted into a disulphuret of lead, composed of

2 atoms lead . .	26
1 atom sulphur .	2
	28

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18. Sulphuret of copper. I have already shown in a former chapter of this work, that there are three sulphurets of copper: Copper,

(1.) Disulphuret, composed of

2 atoms copper . .	8
1 atom sulphur . .	2
	10

This sulphuret is obtained when sulphate of copper is heated in a charcoal crucible, as Berthier has shown. During the process, one-half of the sulphur in the salt makes its escape. It is obtained likewise when sulphur and copper are heated together: the combination is accompanied by combustion. This sulphuret has a bluish black colour, and occurs native, being the glance copper ore of mineralogists.

(2.) Sulphuret of copper has not yet been formed artificially; but it exists in copper pyrites, which H. Rose has shown to be a compound of

1 atom sulphuret of copper	6
1 atom sulphuret of iron	5 5
	11·5*

This sulphuret is a compound of

1 atom copper . .	4
1 atom sulphur .	2
	6

* Ann. de Chim et de Phys. XXV. 197.

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(3.) Bisulphuret of copper. It is formed when any of the salts of copper are precipitated by a current of sulphuretted hydrogen gas. The precipitate is at first brown, but becomes black when dried. Its constituents are

1 atom copper	4
2 atoms sulphur	4
	8

Bismuth,

19. Sulphuret of bismuth. This compound is easily formed by melting bismuth and sulphur together in a close vessel. It exists native, and is known by the name of bismuth glance. It has a light lead grey colour, and the metallic lustre. It occurs in small prismatic striated crystals, so minute that their form has not been recognised. It is much more difficult of fusion than bismuth. Its constituents are

1 atom bismuth .	9
1 atom sulphur .	2
	11

20. Sulphuret of mercury. Two sulphurets of mercury are known. The protosulphuret is formed when a current of sulphuretted hydrogen gas is passed through a solution of protonitrate of mercury; or still better, when the protonitrate of mercury is mixed with a solution of hy-

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drosulphuret of potash. The precipitate is a black powder, similar in appearance to protoxide of mercury, but composed of

1 atom mercury	.	25
1 atom sulphur	.	2
		27

The persulphuret of mercury is obtained when a solution of corrosive sublimate is decomposed by a current of sulphuretted hydrogen gas. The precipitate is black, and bulky; but when sublimed, it assumes a deep red colour, and becomes the pigment well known by the name of cinnabar. It assumes a scarlet colour when reduced to powder; and the colour becomes the lighter the finer the powder is. The constituents of cinnabar are

1 atom mercury	.	25
2 atoms sulphur	.	4
		29

21. Sulphuret of silver. This compound is easily formed by heating sulphur and silver together. It has a lead grey colour, the metallic lustre, possesses malleability and sectility, and is much more easily fused than pure silver; it occurs native, and crystallized. The primary form of the crystals is probably the cube. Its constituents are Silver,

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1 atom silver	.	13·75
1 atom sulphur	:	2
		15·75

Gold, 22. Sulphuret of gold. Oberkampf made us first acquainted with the sulphuret of gold. He obtained it by precipitating nitro-muriate of gold with sulphuretted hydrogen gas. From his experiments it appears to be a trisulphuret, composed of

1 atom gold	. .	25
3 atoms sulphur	.	6
		31

But the experiments of Oberkampf were repeated unsuccessfully by Javal and Berzelius. Berzelius found that the sulphur was acidified at the expense of the oxygen in the oxide of gold existing in the solution.

Platinum, 23. Sulphuret of platinum. There are two sulphurets of platinum. When ammonio-muriate of platinum is mixed intimately with sulphur, and the mixture heated in close vessels till the sal-ammoniac flies off and the excess of sulphur, a bisulphuret of platinum is formed. It is grey coloured, and assumes the metallic lustre when rubbed against a hard body. Its constituents are

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1 atom platinum	.	12
2 atoms sulphur	.	4
		16

When the bisulphuret of platinum is exposed to a higher temperature, one-half of the sulphur is driven off, and a sulphuret of platinum remains, composed of

1 atom platinum	.	12
1 atom sulphur	.	2
		14

The external appearance of the two sulphurets of platinum is nearly the same.

24. Sulphuret of rhodium. When the triple salt of rhodium is mixed with a solution of hydrosulphuret of potash, no precipitate appears at first; but, if the liquid be heated, a dark brown powder falls, which becomes black when dried. From the experiments of Berzelius it would appear, that this sulphuret is composed of Rhodium,

1 atom rhodium	.	5·5
1 atom sulphur	.	2
		7·5

Dr. Wollaston found that rhodium and sulphur unite together when heated. The sulphuret thus formed is bluish grey, and has the metallic lustre; and may be deprived of its sulphur by

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being kept red hot in the open air. From an experiment of Vauquelin, there is reason to consider this as a similar sulphuret with the preceding. He found it a compound of 4 parts rhodium and 1 sulphur. Now, this is nearly 1 atom of rhodium + ⅓ atom of sulphur.

Palladium, 25. Sulphuret of palladium. This sulphuret is easily formed by heating together palladium and sulphur, or by passing a current of sulphuretted hydrogen gas through a solution of palladium. The sulphuret is greyish white, possesses the metallic lustre, and is a compound of

1 atom palladium	.	7
1 atom sulphuret	.	2
		9

Uranium, 26. Sulphuret of uranium. I have made no experiments on this sulphuret. It was obtained by Rose, by passing a current of bisulphuret of carbon, in the state of vapour, over protoxide of uranium, heated to redness in a porcelain tube. It was black, and when rubbed by a hard body it assumed the metallic lustre. It has not been analyzed; but is probably a compound of

1 atom uranium	.	26
1 atom sulphur	.	2
		28

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27. Sulphuret of antimony. This sulphuret is easily formed by heating antimony and sulphur mixed together in a close vessel; but it exists native in abundance, being the common ore of antimony. It has the metallic lustre, a leaden grey colour, and is crystallized. The primary form of the crystals is a right rhombic prism, with angles of 88° 30′, and 91° 30′. Its constituents are Antimony,

1 atom antimony	.	5·5
1 atom sulphur	.	2
		7·5

28. Sulphuret of chromium. I have made no experiments on this sulphuret. Berzelius states, in his Lärbok i Kemien,* that it may be formed by passing a current of the vapour of bisulphuret of carbon over protoxide of chromium, raised to a white heat in a porcelain tube. Its colour is light grey, without any metallic lustre; and when pounded in a mortar, it gives a black powder. When treated with nitric acid, it may be converted into neutral sulphate of chromium. Hence its constituents are Chromium,

1 atom chromium	.	3·5
1 atom sulphur	.	2
		5·5

* II. p. 165.

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Molybdenum,

29. Sulphuret of molybdenum. This sulphuret exists native, and is known by the name of molybdena. It has a leaden colour, and is composed of laminæ, which are soft and flexible; and occasionally occur crystallized, in six-sided prisms. It is a bisulphuret, and composed of

1 atom molybdenum	.	6
2 atoms sulphur	.	4
		10

Tungsten,

30. Sulphuret of tungsten. I have made no experiments on this compound. Berzelius informs us, that tungsten combines with sulphur in two proportions. He formed one of these compounds by mixing cinnabar and tungstic acid intimately together in a crucible, covering the mixture with charcoal powder and a lid, and then keeping the whole in a white heat for half an hour. The sulphuret is a black powder, which assumes the metallic lustre when rubbed against a hard body. Berzelius says it contains 25 per cent. or ¼th of its weight of sulphur. Hence it was a bisulphuret, composed of

1 atom tungsten	.	15·75
2 atoms sulphur	.	4
		19·75

When tungstic acid is dissolved in hydrosulphuret of potash, and precipitated by an acid, a sul-

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phuret is obtained, containing a greater proportion of sulphur. It has a dark yellow colour, and is slightly soluble in water. When heated, it gives out a little water, and its excess of sulphur, and becomes bisulphuret of tungsten.*

31. Sulphuret of columbium. Rose obtained this compound by passing a current of the vapour of bisulphuret of carbon over the oxide of columbium, heated to whiteness in a porcelain tube. It has a dark grey colour, and assumes the metallic lustre when rubbed against a hard body. From Rose's experiments it is obviously a compound of Columbium,

1 atom columbium	.	18
1 atom sulphur	.	2
		20

32. Sulphuret of titanium. I have already, in a preceding chapter of this work, given an account of M. H. Rose's experiments on the sulphuret of titanium; and given my reasons for considering it as a compound of Titanium,

1 atom titanium	.	4
1 atom sulphur	.	2
		6

33. Sulphuret of tellurium. According to Tellurium,

* Lärbok i Kemien, II. 179.

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Klaproth, there are two sulphurets of tellurium. The protosulphuret is steel grey, and has the metallic lustre. When this sulphuret is fused with an additional quantity of sulphur, a leaden coloured sulphuret is formed, having a crystalline texture, and containing a maximum of sulphur.

Arsenic, 34. Sulphuret of arsenic. There are two sulphurets of arsenic which have been long known, and both of which occur in the mineral kingdom.

(1.) Protosulphuret of arsenic (realgar) is formed when sulphur and metallic arsenic are heated together in close vessels, and the heat continued till the excess of sulphur is driven off. It is transparent, has a ruby red colour, and is a compound of

1 atom arsenic	4·75
1 atom sulphur	2
	6·75

(2.) Sesquisulphuret of arsenic (orpiment) is obtained when a solution of arsenic in muriatic acid is precipitated by sulphuretted hydrogen: a yellow powder falls, which is a compound of

1 atom arsenic	4·75
1½ atom sulphur	3
	7·75

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CHAP. XVII.

OF THE MURIATES AND CHLORIDES.

The knowledge of the composition of muriatic acid and the theory of chlorides, for which we are indebted to Sir H. Davy, constitutes, in my opinion, one of the greatest improvements of modern chemistry. It was only advanced by its great discoverer in general terms; and though Dr. John Davy afterwards published a most admirable paper on the chlorides, containing a very great number of experiments, the exactness of which I am enabled to testify from having repeated almost the whole of them; something seems still wanting to enable the chemist to see the connection between the muriate and chloride of the same base. I conceive, therefore, that the facts which I have determined experimentally upon this subject will be acceptable to chemists in general, and of considerable service in the analytical branch of the science.

Action of muriatic acid on metals.

1. A few only of the alkalifiable combustibles are acted upon rapidly by muriatic acid. It dissolves iron, zinc, tin, and antimony with considerable facility. During the solution of these metals, exactly the volume of hydrogen gas is

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evolved which ought to have been combined with the oxygen, requisite to convert them into protoxides, supposing that this oxygen had been in the state of water. The reader will recollect that the atomic weights of these bodies are as follows:

Iron .	3·5
Zinc .	4·25
Tin .	7·25
Antimony	5·5

Now, 3·5 grains of iron, 4·25 grains of zinc, 7·25 grains of tin, and 5·5 grains of antimony, supposing these metals pure, give out, when dissolved in muriatic acid, exactly the same volume of hydrogen gas; namely, about 5·9 cubic inches or $\frac{1}{8}$ of a grain. There seems no doubt from this, that these metals during their solution combine with oxygen, and that they derive this oxygen from water, which is decomposed precisely as when iron or zinc is dissolved in sulphuric acid, the oxygen uniting to the metal, and the hydrogen flying off.

It would indeed be equally possible to account for the evolution of the hydrogen gas by conceiving the chlorine of the muriatic acid to combine with the metal, while its other ingredient, the hydrogen, escapes under the form of gas; for the volume of hydrogen evolved on either suppositions, would be precisely the same; but

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what makes the notion, that the hydrogen comes from water decomposed, preferable to the other is, that these metals cannot be thrown down from the muriatic solution in any other state than that of oxides.

Copper dissolves, likewise, in muriatic acid; but very slowly, and without any sensible effervescence. The solution is brown and opaque, and the copper is at least chiefly in the state of suboxide. I suppose the theory of this solution the same as of the others, and that the want of visible effervescence is to be ascribed to the slowness of the process; for more than a week elapses before a few grains of copper can be dissolved in this acid.

Difference between muriates and chlorides.

2. Most of the alkaline bases combine with muriatic acid very readily, and without any apparent alteration either in the acid or base. I suppose that all these combinations (or almost all of them) while in solution, are in the state of muriates, or that they are compounds of muriatic acid, and the base unaltered. Whether they continue muriates after they are separated in crystals or in powder, depends upon circumstances, and can only be known by an examination of every particular compound. I shall, therefore, take a review of all these compounds which I have examined, and point out their various states as far as I have been able to determine them.

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1. Muriate of ammonia. This salt I find, when obtained in the usual way by sublimation, is anhydrous, and is a compound of

1 atom muriatic acid	4·625
1 atom ammonia	2·125
	6·75

The water found in this salt by Dr. Murray was no doubt accidental. It has an affinity for water, and even deliquesces if kept in a damp place; but the quantity of water found not amounting to an atom, it is obvious that it cannot be considered as a chemical constituent of the salt.

Chlorides of potassium and sodium.

2. Muriate of potash and muriate of soda exist only in solution—when separated by evaporation in the state of crystals, they are no longer muriates but chlorides; for 9·776 grains of the crystals, usually called muriate of potash, when exposed to a red heat lose 0·276 grain of water, and leave 9·5 grains of the fused salt; and when these 9·5 grains of salt are dissolved in water, and thrown down by nitrate of silver, the chloride of silver after fusion weighs just 18·25 grains, equivalent to 4·5 grains of chlorine. It is obvious then, that the crystals must be composed of

1 atom chlorine	4·5
1 atom potassium	5
	9·5

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The water, amounting to rather less than $\frac{1}{4}$th of an atom, can only be mechanically interposed between the plates of the crystals, and not in chemical combination.

Similar experiments were made with common salt with exactly the same result.

Hence, the crystals of both these salts are chlorides of potassium and sodium, with a little water lodged mechanically between their plates. No crystallized muriate of potash or soda exists.

3. Muriate of barytes. This salt usually crystallizes in tables consisting of very short four-sided prisms with square bases. It is not altered by exposure to the air, and is composed of Muriate

1 atom muriatic acid	4·625
1 atom barytes	9·750
1 atom water	1·125
	15·5

When 15·5 of this salt are heated to redness in a platinum crucible, the loss of weight amounts to 2·25, equivalent to two atoms of water, and chloride of barium remains weighing 13·25, and composed of and chloride of barytes.

1 atom chlorine	4·5
1 atom barium	8·75
	13·25

We may either consider the crystals as composed

of 1 atom chloride of barium and 2 atoms water, or of 1 atom of anhydrous muriate of barytes and 1 atom water. From the phenomena which take place when barytes is dissolved in muriatic acid, I adopt the second hypothesis as the simplest; indeed, whenever a salt belonging to this genus contains water of crystallization, I conceive it to be simplest, and therefore best to consider it as a muriate. A red heat, if it can resist such a temperature, not only drives off all the water of crystallization, but causes the hydrogen of the acid to unite with the oxygen of the base, and to fly off likewise in the state of water, leaving the salt in the state of a chloride. For it is worthy of remark, that whenever the base is a deutoxide, the salt contains two atoms of muriatic acid or is a bimuriate.

Muriate

4. Muriate of strontian. This salt crystallizes in very long white needles, which when viewed by the microscope have the form of hexagonal prisms. It is more soluble in water than muriate of barytes, and likewise soluble in alcohol, which muriate of barytes is not. Its constituents are

1 atom muriatic acid	4·625
1 atom strontian	6·5
8 atoms water	9
	20·125

When 20·125 of it are heated, they lose 10·125

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of their weight, which is equivalent to 9 atoms water, and there remain 10 of chloride of strontium, composed of

and chloride of strontium.

1 atom chlorine	4·5
1 atom strontium	5·5
	10

5. Muriate of lime. This salt is easily formed by saturating muriatic acid with lime. It is so soluble and deliquescent as not to be easily crystallized. Yet I have frequently obtained it in regular transparent crystals—and they may be obtained at any time by putting a strong solution of it under the exhausted receiver of an air pump, along with sulphuric acid to absorb the vapour as it flies off. These crystals are four-sided or six-sided prisms, striated longitudinally, and bearing a considerable resemblance to the crystals of sulphate of soda. The constituents of these crystals are the following:

Muriate of lime

1 atom muriatic acid	4·625
1 atom lime	3·5
6 atoms water	6·75
	14·875

When these crystals are exposed to a red heat, not only the water, but a portion of the acid is apt to make its escape. However, I have repeatedly succeeded in rendering the crystals an-

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hydrous without destroying their subsequent solubility in water, and consequently, without any loss of acid. In such cases, 14·875 lost 7·875, which is equivalent to 7 atoms water.

and chloride. The 7 of chloride of calcium remaining are composed of

1 atom chlorine	4·5
1 atom calcium	2·5
	7

Muriate of magnesia 6. Muriate of magnesia. This salt is easily obtained by saturating muriatic acid with magnesia. The solution is colourless, has a hot, biting taste, and is not easily crystallized. However, I have obtained it from a manufacturer of Epsom salt in pretty large four-sided prisms, apparently with square bases, but too irregular to admit of measurement. These crystals deliquesce when exposed to the air; they are composed of

1 atom muriatic acid	4·625
1 atom magnesia	2·500
5 atoms water	5·625
	12·75

When exposed to heat in a close vessel, they not only lose their water but a portion also of their acid. However, a considerable portion remains undecomposed, and converted into chloride of magnesium. If we make allowance for

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the decomposed portion, then 12·75 parts of this salt in crystals lose 6·75 parts, which is equivalent to 6 atoms of water, and there remain 6 parts of chloride of magnesium, composed of and chloride.

1 atom chlorine	4·5
1 atom magnesium	1·5
	6

When this chloride is thrown into water, a hissing noise takes place as when a red hot iron is plunged into water; a great deal of heat is evolved, and the whole is gradually dissolved, leaving behind always a portion of pure magnesia, which I subtracted in the preceding statements.

7. Muriate of alumina. This salt is easily obtained by saturating muriatic acid with hydrate of alumina. It is a beautiful white matter, without any appearance of a crystalline texture. Its constituents are Muriate of alumina.

1 atom muriatic acid	4·625
1 atom alumina	2·250
3 atoms water	3·375
	10·25

This salt cannot be converted into a chloride of aluminum by heat; when we make the experiment, not only the water, but the whole of the acid is driven off, leaving the alumina behind in

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a state of purity. Chloride of aluminum is still unknown.

Bucholz, in his Beitrage, (III. 111.) gives us an analysis of this salt. He states its constituents as follows:

Muriatic acid . .	29·8
Alumina . . .	30·0
Water . . .	40·2
	100·0

Dimuriate. I have never obtained any salt whose constituents approached those given by Bucholz. His salt seems to have been a dimuriate composed of

1 atom muriatic acid	4·625	or	29·13
2 atoms alumina .	4·5	-	28·35
6 atoms water .	6·75	-	42·52
	15·875		100·00

For, considering the imperfection of the data which Bucholz employed, the deviations in his analysis, from these numbers, are not greater than might have been expected. What renders the existence of this dimuriate more probable, is, that alumina has the property of uniting in the same way with some other acids.

Muriate of iron 8. Protomuriate of iron. This salt is easily formed by dissolving pure iron filings in muriatic acid in a retort, and setting aside the solution: the salt crystallizes spontaneously, and the super-

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natant liquid prevents the absorption of oxygen by it. Protomuriate of iron has a light green colour, exactly similar to that of protosulphate of iron; its taste is sweetish and astringent; it has the form of rhombic plates, which do not deviate far from a right angle, but I was not able to measure them. They are soluble both in water and alcohol. I never could succeed in preserving the solution for any time without alteration, but have kept the dry crystals for a considerable time in a well stopped phial without their undergoing any alteration. The constituents of this salt are as follows:

1 atom muriatic acid .	4·625
1 atom protoxide of iron	4·500
3 atoms water .	3·875
	12·5

When 12·5 parts of this muriate are heated sufficiently without the contact of air, the loss of weight is 4·5 parts, equivalent to 4 atoms of water, and there remain behind 8 parts of chloride of iron, composed of

and chloride.

1 atom chlorine . .	4·5
1 atom iron . .	3·5
	8

The chloride, thus formed, has a grey colour, a good deal of lustre, and a lamellar texture. I

have never succeeded in converting the whole of any portion of protomuriate of iron into chloride: on dissolving the chloride in water there always remains more or less of oxide, so that a portion of the muriatic acid is disengaged by the heat; but in the above statement this decomposition was allowed for—the portion decomposed being abstracted from the original weight of salt employed.

Muriate of manganese

9. Protomuriate of manganese. This salt is easily formed by dissolving carbonate of manganese in muriatic acid. It is not easily crystallized: however, by very careful concentration of the solution I have obtained very short six-sided prisms, two opposite faces of which were much larger than the other four. The taste of this salt, like that of the other salts of manganese, has some resemblance to that of sulphate of soda; it is very soluble both in alcohol and water, and is an exceedingly deliquescent salt. Its constituents, when dried by pressure between folds of blotting paper, are as follows:

1 atom muriatic acid .	4·625
1 atom protoxide of manganese	4·5
4 atoms water . .	4·5
	13·625

When 13·625 parts of it are heated just to redness, they lose 5·625 parts of their weight,

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equivalent to 5 atoms water, and the remaining 8 parts consist of chloride of manganese. This chloride has a red colour and a lamellar texture, and is a beautiful looking substance when first formed. Its constituents are obviously

and chloride.

1 atom chlorine . .	4·5
1 atom manganese . .	3·5
	8

The protomuriate of manganese is apt to be partly decomposed when heated; but in the above statement the portion of the salt thus decomposed is supposed to be withdrawn.

10. Green muriate of copper. This muriate is easily obtained by dissolving the black oxide of copper in muriatic acid, and concentrating the solution. It forms long crystals, consisting of four-sided rectangular prisms of a fine grass green colour. Its taste is exceedingly disagreeable, and when exposed to the air it soon deliquesces. Its constituents are as follows:

Green muriate of copper

1 atom muriatic acid	4·625
1 atom black oxide of copper	5·000
2 atoms water . .	2·250
	11·875

When 11·875 parts of this salt are exposed to a heat of about 400° they lose 3·375 of their

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weight, equivalent to three atoms water, and a yellowish brown matter remains, weighing 8·5 parts, which is a chloride of copper. It is composed of

and chloride.

1 atom chlorine . .	4·5
1 atom copper . .	4
	8·5

This chloride dissolves readily in water, and may be again obtained in the state of muriate of copper.

Dimuriate

11. White muriate of copper. If we mix together copper in the state of fine powder in which it is obtained by precipitating it from its solutions by a plate of zinc, and black oxide of copper also in a fine powder, in the proportion of 4 parts of the former to 5 of the latter; put the mixture into a phial, and pour on it a quantity of concentrated muriatic acid; an intense action takes place at once, great heat is evolved, and a dark coloured opaque solution is formed in a few minutes. If the phial be well corked and placed in an inverted position, a great number of very small crystals are speedily deposited in the form of white grains; but in a more dilute solution I have obtained pretty large white octahedral crystals. These crystals consist of suboxide of copper united to muriatic acid; they contain water of crystallization, but I have not ascer-

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tained how much. When heated to redness in a close vessel, they are converted into a dichloride of copper, composed of

1 atom chlorine . .	4·5
2 atoms copper . .	8
	12·5

In general, there is a slight excess of copper, because a portion of the chlorine is driven off during the process. By Berzelius' analysis, the constituents were

and dichloride.

Chlorine . .	4·5
Copper . .	8·316 *

Here the excess of copper was about $\frac{1}{27}$th part or nearly $\frac{1}{12}$th of an atom. I have formed this chloride with a still smaller excess of copper than Berzelius did; but I never was able to get it absolutely free from all excess of copper, owing to the cause just specified.

12. Muriate of nickel. This salt has a fine grass green colour, and crystallizes readily enough; but so irregularly, that I have not been able to determine the shape of the crystals, though they are prismatic, and I believe composed of four-sided prisms. They deliquesce when exposed to the air; when heated, they readily lose their water, and are converted into chloride

Muriate of nickel

* Ann. de Chim. LXXVIII. 118.

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of nickel. The crystals, carefully dried on blotting paper, are composed of

1 atom muriatic acid .	4·625
1 atom protoxide of nickel	4·25
5 atoms water . .	5·625
	14·5

When 14·5 grains of these crystals are heated cautiously in a retort, they lose 6·75 grains of water (equivalent to 6 atoms), and assume a golden colour. In this state they constitute a chloride of nickel, composed of

and chloride.

1 atom chlorine .	4·5
1 atom nickel .	3·25
	7·75

When this chloride is exposed to the air, it absorbs moisture, and is gradually restored to its original state of muriate of nickel.

Muriate of cobalt

13. Muriate of cobalt. This salt is easily obtained by saturating muriatic acid with carbonate of cobalt, and concentrating the solution sufficiently. When set aside, it deposites beautiful garnet red crystals (probably rhombs, but the shape could not be well made out), which deliquesce when exposed to the air. When these crystals are heated, they melt in their water of crystallization; and, giving out water, the liquid assumes a fine deep blue colour. If we continue

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the heat in a close vessel, the whole water is driven off, and a smalt blue coloured chloride of cobalt remains in a hard mass, which readily dissolves in water, forming a red coloured solution. When the solution of muriate of cobalt is dilute, it has a red colour; but when very much concentrated by evaporation, the colour becomes blue—or green, if iron or nickel be present in the liquid. This change of colour takes place more readily if an excess of acid be present in the liquid. The crystallized muriate of cobalt is composed of Chloride.

1 atom muriatic acid .	4·625
1 atom protoxide of cobalt	4·250
4 atoms water . .	4·500
	13·375

When 13·375 grains of these crystals are heated, they give out 5·625 grains of water, equivalent to 5 atoms; and there remain 7·75 grains of blue coloured chloride of cobalt.

14. Muriate of zinc. Muriatic acid dissolves zinc with facility; but the solution cannot be made to crystallize. When kept for some time on the sand bath till it ceased to lose weight, it concreted, on cooling, into a white opaque matter, having a very strong and disagreeable taste, and speedily deliquescing, when exposed to the air. It was analyzed by dissolving a given Muriate of zinc,

weight in water, and precipitating the oxide of zinc by an alkali, and the muriatic acid by nitrate of silver. Its constituents are

1 atom muriatic acid	4·625
1 atom oxide of zinc	5·25
	9·875

Chloride.

If 9·875 of this muriate be very cautiously heated in a glass tube, it may be made to give out 1·125 of water, equivalent to an atom. Of course, it has become a chloride of zinc, composed of

1 atom chlorine .	4·5
1 atom zinc . .	4·25
	8·75

This is the only muriate which I have met with, except sal-ammoniac, containing no water of crystallization. When chloride of zinc is heated to redness, it fuses into a transparent liquid. In a red heat it may be sublimed in the open air, giving out a peculiar and not unpleasant odour.

Muriate of cadmium,

15. Muriate of cadmium. A strong solution of muriate of cadmium, committed to spontaneous evaporation, is gradually converted into a mass of short, satiny crystals, somewhat resembling asbestus. 25·29 grains of this salt, decomposed by carbonate of soda, gave 14·59 grains

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of ignited oxide. Hence the constituents of the salt are

1 atom muriatic acid .	4·625
1 atom oxide of cadmium	8
1 atom water . .	1·125
	13·75

When 13·75 grains of the crystals are heated in the sand bath, they give out 2·25 grains of water, equivalent to 2 atoms, and become 11·5 grains of chloride of cadmium, obviously composed of Chloride.

1 atom chlorine .	4·5
1 atom cadmium .	7
	11·5

16. Bimuriate of tin. When tin is dissolved in muriatic acid, and the solution sufficiently concentrated, crystals are deposited, usually in the form of plates. They are white and brilliant, have a disagreeable taste, and are soluble in water. The constituents of these crystals I find to be Bimuriate of tin.

2 atoms muriatic acid .	9·25
1 atom peroxide of tin .	9·25
3 atoms water . .	3·375
	21·875

I have not attempted to convert these crystals into bichloride of tin. There exists also a proto-

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muriate of tin; but it is not easily got in a state fit for analysis.

Chloride of lead.

17. The muriate of lead does not exist. When acetate or nitrate of lead is mixed with a solution of common salt, and the liquid concentrated somewhat, and then set aside, long white needle formed crystals are deposited. These crystals have a silky lustre. When examined before the microscope, they appear to be flat four-sided prisms, terminated by oblique summits. They have very little taste; and are very sparingly soluble in cold water, though boiling water dissolves a considerable quantity of them. When these crystals were exposed to the greatest heat that I could raise in my sand bath, they lost no weight. When heated to redness in an open vessel, they sublime almost entirely; but, in a close vessel, they may be heated to redness, fused, and converted into *plumbum corneum*, without any loss of weight. This plumbum corneum is a chloride of lead, composed of

1 atom chlorine . .	4·5
1 atom lead . .	13
	17·5

Chlorides of mercury.

18. Neither of the oxides of mercury is capable of uniting with muriatic acid; for both calomel and corrosive sublimate are chlorides. It is needless to enter into any details respect-

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ing these well known substances. Their constituents, as determined by numerous experiments, are as follows:

(1.) Calomel or protochloride of mercury,

1 atom chlorine	.	4·5
1 atom mercury	.	25
		29·5

(2.) Corrosive sublimate or perchloride of mercury,

2 atoms chlorine	.	9
1 atom mercury	.	25
		34

Chenevix's analysis of calomel is very near the truth, but his analysis of corrosive sublimate is not quite so accurate—that of Zaboada is the best which I have seen.

19. Neither does the oxide of silver combine with muriatic acid. The precipitate from nitrate of silver by common salt, when well washed and dried in the open air, loses, when fused, about 2 per cent. of water. Now, this small fractional part of an atom of water can only have been mechanically attached to the precipitate. This precipitate is a chloride of silver, composed of Chloride of silver.

1 atom chlorine	.	4·5
1 atom silver	.	13·75
		18·25

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as I have satisfied myself by the most careful experiments.

No general principles respecting the constitution of muriates can be deduced from the salts belonging to that genus whose constitution is known; but it may be worth while to state the facts in a few simple propositions.

Conclusions.

(1.) There are five bases which do not seem capable of combining with muriatic acid except in solution. These are

1 Potash,
2 Soda,
3 Lead.
4 Mercury,
5 Silver.

The combinations which they form, when in the state of crystals or precipitates, are chlorides.

(2.) All the muriates contain water of crystallization, except sal-ammoniac and muriate of zinc.

(3.) Muriates exist, containing

1 atom water.	Muriates of barytes, cadmium.
2 atoms water.	Muriate of copper.
3 atoms water.	Muriate of alumina, protomuriate of iron, bimuriate of tin.
4 atoms water.	Muriate of manganese, cobalt.
5 atoms water.	Muriates of magnesia, nickel.
6 atoms water.	Muriate of lime.
8 atoms water.	Muriate of strontian.

The great variation in the quantity of water in these salts is astonishing.

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The muriate of barytes contains the smallest proportion of water; it amounts only to 7·258 per cent. The muriate of lime contains the greatest quantity; it amounts to 45·378 per cent. As it may be useful in some cases to know the quantity of water contained in 100 parts of these salts, I shall set it down in the following table: Water of crystallization per cent.

Muriate of barytes .	7·258
- - cadmium .	8·182
- - tin . .	15·424
- - copper .	18·947
- - iron . .	27
- - alumina .	30
- - manganese .	33·027
- - cobalt .	33·644
- - nickel .	38·793
- - magnesia .	44·117
- - strontian .	44·720
- - lime . .	45 378

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CHAP. XVIII.

OF THE COMPOSITION OF THE SALTS.

It was an opinion advanced long ago by Wentzel, that it was only necessary to determine what we at present call the atomic weight of the acids and bases, which constitute the salts, in order to be able to draw up tables exhibiting the constituents of all of them, without being at the trouble to subject them to a chemical analysis. Berzelius has followed up this idea; and after determining the atomic weights of the acids and bases by a very careful analysis of a certain number of salts, he drew up a complete set of tables, exhibiting the proportion of acid and base contained in all the known salts. But such tables, even supposing the atomic weights on which they are founded to be perfectly exact, can be of little utility to chemists; for they contain no new information whatever. They merely state the known ratio between the acid and base in numbers different from those attached to these bodies, and representing their atomic weights. Now, when we have occasion to use these ratios for calculating the result of a chemical experiment, it is in general much easier

Berzelius' tables of salts.

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to have recourse to the atomic weights themselves than to the proportions of the constituents contained in 100 parts of the salt. To give an example:

Atom of sulphuric acid	5
Atom of protoxide of lead	14
Of sulphate of lead	19

Now, the constituents of sulphate of lead per cent. are

Sulphuric acid	26·3158
Protoxide of lead	73·6842
	100·0000

Suppose I have 86 grains of sulphate of lead, and that I wish to know how much sulphuric acid it contains: it is easier to use the proportion

19 : 5 : : 86 : 22·63 = oxide of lead required,

than the proportion

100 : 26·3158 : : 86 : 22·63 = oxide of lead.

or if the second process be sometimes as short as the former, the former has the advantage of always giving a precise result, whereas the latter in general is only an approximation. This has induced me for sometime to abandon the old mode of stating the constituents of salts in the proportions contained in 100 parts of the salt,

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and to substitute the atomic weight of each constituent. This conveys a more precise idea of the constitution of the salt, and gives us at the same time the atomic weight of an integrant particle of it. This method will come to be adopted likewise in the analysis of minerals, as soon as we have acquired more definite ideas respecting the chemical constitution of these complex bodies—a kind of knowledge into which great progress of late years has been made by Berzelius and his pupils, and capable even at present of a satisfactory developement with regard to many minerals.

Utility of such tables.

The great use of a table of the composition of the salts is to give us an exact knowledge of the weight of each constituent contained in a given weight of the salt. For example, carbonate of soda is a compound of

1 atom carbonic acid	2·75
1 atom soda	4
10 atoms water	11·25
	18

I am in the habit of keeping carbonate of soda in my laboratory in two states; namely, in crystals and anhydrous. If I want exactly 4 grains of soda for any particular purpose, I have only to employ 18 grains of the crystallized carbonate, or 6¾ grains of the anhydrous carbonate; in either case I am sure of having exactly the

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quantity of soda required: whereas, if I were obliged to employ caustic soda, it would not be so easy to determine how much of it contained the exact quantity of soda required. But it is obvious, that no table exhibiting the composition of the salts can furnish us with any information which will be useful in this point of view, unless it tells us whether the salts are anhydrous; and, if they contain water, how many atoms of that liquid enter into the integrant particle of the salt. No general laws respecting the water of crystallization being known, it is still necessary to subject every salt to a rigid analysis in order to determine whether any water be present in it, and how much.

I have made a very considerable number of analyses with this object in view, and I shall state the results of them in this chapter. Now, salts are of two different kinds—some are composed of an acid and a base simply united together, with or without water: these may be called simple salts. Others are formed by the union of two simple salts together, and this either with or without an alteration in the atomic quantity of water present. These salts are usually called *triple salts*; but the term *double salts*, applied to them by Berzelius, is much more appropriate. These double salts are exceedingly numerous, though only a few of them have been noticed in chemical books. It will be

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convenient to consider the simple salts in the first place, because a knowledge of them is necessary in order to understand the constitution of the double salts.

SECT. I.

OF THE SIMPLE SALTS.

M. Gayton-Morveau, to whom the science of chemistry is indebted for the present nomenclature of the salts, divided them into as many genera as there were acids, and gave each genus a name derived from that of the acid belonging to it. Bergman, who had contrived a Latin nomenclature for the salts some years before the appearance of Morveau's nomenclature, on the other hand, divided them into as many genera as there were bases, and derived the generic names from that of the base. In this plan he was followed by Dr. Black. Both of these methods of arranging the salts have their advantages and disadvantages. In reality, which ever mode we adopt, we clap under the same genus, salts possessing very different and almost opposite properties. At present I shall follow Bergman's method, because I have arranged the salts according to it in my System of Chemistry. In general I shall merely give the constituents of

each salt without making any observations on its properties, except when they may be necessary, when speaking of salts not previously accurately described in chemical books.

1. SALTS OF AMMONIA.

1. Sulphate of ammonia. Its constituents are

1 atom sulphuric acid	5
1 atom ammonia	2·125
1 atom water	1·125
	8·25

Mode of analysis.

The specimen analyzed was in large and beautiful crystals prepared expressly for the purpose. My method was this: 8·25 grains were dissolved in water, and the liquid mixed with a solution of 13·25 grains of chloride of barium. After the sulphate of barytes had precipitated, the residual liquid was examined for barytes and sulphuric acid, but found to contain no traces of either; hence, 8·25 grains of the salt contain 5 grains of sulphuric acid. The remaining 3·25 grains constitute the ammonia and water. The salt was neutral; consequently, 2·125 of ammonia must have been present to saturate the 5 of sulphuric acid. The remaining 1·125 was obviously water. I mention these particulars because Berzelius, in the tables of the constituents of salts which he published, has stated that the sulphate of ammonia contains 23·91 per cent. of

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water, (the result of his analysis was 23·3.*) Now it is obvious, that the salt which I analyzed contained per cent.

Sulphuric acid	60·606
Ammonia	25·757
Water	13·636
	99·999

Berzelius' salt, therefore, must have contained two atoms of water. The salt which I analyzed was composed of regular rectangular plates with bevilled edges, and from some observations on the crystals, I am induced to consider their primary form as a four-sided rectangular prism with square bases. It would seem from Berzelius' analysis, that there is another sulphate of ammonia, containing twice as much water as the salt which I analyzed. It is the only form of the sulphate of ammonia with which I am acquainted. I wish Berzelius had mentioned the shape of the crystals which he examined.

Mode of analysis.

2. Nitrate of ammonia. To ascertain the composition of this salt I put a quantity of it into a small retort, from the beak of which a bent tube passed to the top of a graduated glass jar filled with mercury, and standing on the mercurial trough, the apparatus was precisely similar to the one described in chapter sixth, sect. 1st, p.

* Afhandlingar, V. 148.

140, by means of which I determined the volume of carbonic acid gas disengaged from a given weight of calcareous spar. A spirit lamp was applied to the bottom of the retort, by which the salt was melted and decomposed into protoxide of azote and water. The volume of deutoxide of azote evolved was measured; the undecomposed salt was washed out of the retort, and evaporated in the very same temperature as the original salt had been till it ceased to lose weight—it was then weighed. By this means I ascertained the exact quantity of salt decomposed. The reader is probably aware, that when nitrate of ammonia is heated it is completely decomposed into protoxide of azote and water, as was shown many years ago by Sir H. Davy. It is easy to see that this must be the case.

	OXYGEN.	AZOTE.	HYDROGEN.
Nitric acid composed of	5 atoms	+ 1 atom	+ 0 atom
Ammonia . .	0	+ 1	+ 3
Total	5	+ 2	+ 3

Now,

3 atoms water consist of	3	+ 0	+ 3
2 atoms protoxide of azote	2	+ 2	+ 0
Total	5	+ 2	+ 3

So that an integrant particle of nitrate of ammonia (supposing it anhydrous) is decomposed by

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heat into 3 atoms water and 2 atoms protoxide of azote.

3 atoms water weigh	3·375
2 atoms protoxide of azote	5·5
	8·875

8·875 parts of nitrate of ammonia (if anhydrous) would give out, when decomposed, 5·5 parts of protoxide.

The volume of protoxide of azote obtained, enabled me to determine the weight of anhydrous nitrate of ammonia decomposed; and the difference between this weight, and that of the salt decomposed in my experiment, gave me the water of crystallization which my salt contained. The constituents of nitrate of ammonia obtained in this way are as follows:

1 atom nitric acid	6·75
1 atom ammonia	2·125
1 atom water	1·125
	10·000

This is just the quantity of water found by Berzelius in his analysis of this salt.*

Davy analyzed this salt in three states: namely, in prismatic crystals, in a fibrous state, and compact. The result is as follows:

* Ann. de Chim. LXXX. 180.

acid to the atom of ammonia, and constituting, therefore, the salt which I am just going to notice.

4. Sesquicarbonate of ammonia. This is the name which ought to be given to the carbonate of ammonia of the shops. It is usually in the state of hard white cakes, having a strong ammoniacal odour, and instantly giving a purple colour to cudbear paper. I have frequently examined this salt at different times and in different places, to ascertain whether there was any difference in its composition. It is only a sesquicarbonate when newly prepared; by keeping, it gradually loses a portion of its ammonia, and I have obtained it in a great variety of states between a sesquicarbonate and bicarbonate; but never constituting a true bicarbonate. I analyzed this salt in the following manner: Sesquicarbonate,

7·375 grains of it were dissolved in water, and mixed with a solution of 9 grains of oxalic acid crystals. The mixture, when recent, produced no change on cudbear paper, and therefore contained no free ammonia. It reddened *litmus* paper; but the blue colour was speedily restored when the paper was left exposed to the air: hence, it was owing to the carbonic acid disengaged from the ammonia by the oxalic acid. Now, 9 grains of oxalic acid crystals contain 4·5 grains of true acid, which require for saturation 2·125 grains of ammonia. This,

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consequently, is the weight of ammonia in 7·375 grains of sesquicarbonate.

7·375 grains of sesquicarbonate of ammonia were dropped into sulphuric acid, and the carbonic acid gas disengaged was driven through lime water. The weight of the carbonate of lime precipitated was 9·375 grains, equivalent to 4·125 grains of carbonic acid. Hence, the constituents of the salt are

1½ atom carbonic acid	4·125
1 atom ammonia	2·125
1 atom water . .	1·125
	7·375

This salt may be obtained anhydrous by mixing together 3 volumes of carbonic acid gas and 4 volumes of ammoniacal gas.

Bicarbonate,

5. Bicarbonate of ammonia. This salt may be obtained by reducing the sesquicarbonate to powder, and exposing it to the open air for some time in a dry place. It gives out a portion of its ammonia, and at the same time loses its smell. Its constituents, determined in the same way as those of the preceding salt, are

2 atoms carbonic acid	5·5
1 atom ammonia .	2·125
1 atom water . .	1·125
	8·75

It may be obtained anhydrous by mixing equal

volumes of carbonic acid and ammoniacal gases.

6. Borate of ammonia. The constituents of this salt seem to me to be as follows: Borate,

1 atom boracic acid	3
1 atom ammonia .	2·125
2 atoms water . .	2·25
	7·375

I merely satisfied myself that the acid existing in the salt is not more than 1 atom. I then ascertained the weight of the acid, and inferred the other constituents from the deficiency of weight. The above analysis approaches to that of Berzelius.*

7. Phosphate of ammonia crystallizes in rhomboids, and is much less transparent than biphosphate. The constituents of this salt are as follows: Phosphate,

1 atom phosphoric acid	3·5
1 atom ammonia .	2·125
2 atoms water . .	2·250
	7·875

7·875 grains of phosphate of ammonia in crystals were dissolved in water, and mixed with a solution of 20·75 grains of nitrate of lead. After the precipitation of the phosphate of lead, the

* See Annals of Philosophy, III. 57.

residual liquid was not rendered muddy by phosphate of ammonia or nitrate of lead. But a little of the phosphate of lead remains in solution, unless the liquid be evaporated to dryness, and the residue dissolved in water. The consequence of this is, that sulphate of soda renders the residual liquid slightly opalescent.

Biphosphate,

8. The biphosphate of ammonia is composed of

2 atoms phosphoric acid	7
1 atom ammonia . .	2·125
	9·125

9·125 grains of biphosphate of ammonia in crystals were just decomposed by 41·5 grains of nitrate of lead. Hence, the crystallized salt contains no water. This salt forms very beautiful transparent four-sided right prisms with square bases. Taste acid,—reddens vegetable blues.

Arseniate,

9. Arseniate of ammonia crystallizes without any great difficulty; though it has a considerable tendency to pass into binarseniate. Its crystals are regular octahedrons often with an intervening prism between the pyramids. It is anhydrous, and is composed of

1 atom arsenic acid	7·75
1 atom ammonia	2·125
	9·875

For 9·875 grains are just decomposed by 20·75 grains of nitrate of lead.

10. Binarseniate of ammonia. This salt was obtained by dissolving crystallized arseniate of ammonia and dry arsenic acid in water, each in the atomic proportions. The solution being sufficiently concentrated and set aside, large crystals of binarseniate of ammonia were deposited. They were opaque white irregular rhomboids; the taste of the crystals was saline, astringent, and acid, and they strongly reddened vegetable blues. Binarseniate,

19·875 grains of this salt were dissolved in water, and mixed with a solution of 41·5 grains of nitrate of lead. After the arseniate of lead had precipitated, the residual liquid was neither affected by glauber salt nor nitrate of lead. Hence, we see that 19·875 of this salt contain just 2 atoms of arsenic acid. The constituents of the salt consequently are

2 atoms arsenic acid	15·5
1 atom ammonia	2·125
2 atoms water	2·25
	19·875

11. Chromate of ammonia. This salt is not easily obtained in a state of purity, from the great tendency which it has to part with half of its ammonia during its concentration. It may, however, be procured in a solid state by the following process: supersaturate chromic acid with ammonia, and place the solution (which should Chromate,

be concentrated) under the exhausted receiver of an air pump, standing over a vessel filled with concentrated sulphuric acid. The water and excess of ammonia gradually evaporate, and leave the chromate of ammonia behind in a dry state. It has a fine yellow colour, and is in crystalline scales, which are not altered by exposure to the air. Its taste is hot and saline, and it is exceedingly soluble in water; it produces no alteration on cudbear paper, but very slightly reddens litmus paper. Solutions of 8·625 grains of this salt and 20·75 grains of nitrate of lead being mixed together, chromate of lead precipitated, and the supernatant liquid was transparent and colourless, and contained no traces of chromic acid or of lead. Hence, the salt is anhydrous and composed of

1 atom chromic acid	6·5
1 atom ammonia	2·125
	8·625

Bichromate,

12. Bichromate of ammonia. This salt is obtained when we concentrate the solution of chromate of ammonia on the sand bath. One half of the ammonia flies off, and the bichromate gradually precipitates in the form of beautiful red crystalline scales, which are not altered by exposure to the air. The taste of this salt is hot, and bitter, and very disagreeable; it reddens

vegetable blues, and is very soluble in water. When heated it melts and loses its water and ammonia; a dark green matter remains, which speedily becomes solid, exhibiting the rudiments of crystallization on the surface. This matter is brittle, has a cooling and sharp taste, and partly dissolves in water, forming a deep yellow solution, and partly remains in the state of a deep green insoluble matter. It is obvious, that by the heat the chromic acid had been partly converted into protoxide of chromium; so that the dark green matter left was a kind of chromate of chromium.

17·375 grains of this salt were just deprived of the whole of their chromic acid by 41·5 grains of nitrate of lead. Hence, the constituents of the salt are

2 atoms chromic acid	13
1 atom ammonia . .	2·125
2 atoms water . .	2·25
	17·375

13. Bitungstate of ammonia. I have already given an account of this salt in a preceding chapter of this work. Its constituents I believe to be Bitungstate,

2 atoms tungstic acid	37·5
1 atom ammonia .	2·125
2 atoms water . .	2·25
	41·875

I have not analyzed the other species of this salt, which is perhaps a tungstate—not having obtained it in sufficient quantity.

Acetate, 14. Acetate of ammonia. Taste hot and aromatic—crystals transparent four-sided oblique prisms, terminated by a rhomb. Faces apparently striated—very deliquescent, so that they cannot be measured. Analyzed by digesting a solution of 40 grains of the crystals with 40 grains of pure carbonate of lime in fine powder; 15·5 grains of the carbonate of lime had been dissolved, indicating 15·5 grains of acetic acid. Hence, the constituents of the salt are

1 atom acetic acid	6·25
1 atom ammonia	2·125
7 atoms water	7·875
	16·25

This salt was crystallized by placing a concentrated solution of it under the exhausted receiver of an air pump over sulphuric acid. Mr. Rootsey of Bristol crystallized it in that way about eight years ago.

Benzoate, 15. Benzoate of ammonia. This salt forms beautiful crystals, having a silky lustre. I find, that when kept in a carelessly stopped vessel they gradually lose half of their ammonia, and are converted into bibenzoate; but I have not ascertained the water of crystallization of this

last salt. The benzoate is very sparingly soluble in water. Its constituents are

1 atom benzoic acid	15
1 atom ammonia	2·125
1 atom water .	1·125
	18·25

16. Succinate of ammonia. From an analysis of this salt which I made several years ago, I am disposed to consider it as composed of Succinate,

1 atom succinic acid	6·25
1 atom ammonia .	2·125
2 atoms water .	2·25
	10·625

17. Oxalate of ammonia. This salt, being of considerable service in chemical analyses, was examined by me with great care, and its constituents found to be Oxalate,

1 atom oxalic acid	4·5
1 atom ammonia .	2·125
2 atoms water .	2·25
	8·875

18. Binoxalate of ammonia. This salt is easily obtained by adding to a solution of oxalate of ammonia crystals of oxalic acid, in the proportion of 8·875 of the former to 9 of the latter. When the solution is concentrated it yields Binoxalate,

beautiful crystals of binoxalate of ammonia: these crystals are partly octahedrons, partly four-sided flat prisms, apparently rectangular, having two opposite lateral edges usually truncated. Taste acid,—reddens vegetable blues, and is not altered by exposure to the air. When 20·125 grains of these crystals are dissolved in water and mixed with a neutral solution of 12·5 grains of carbonate of lime in muriatic acid, the residual liquid, after the precipitation of the oxalate of lime, is neither affected by oxalate of ammonia nor muriate of lime. Hence, the constituents of the salt are

2 atoms oxalic acid	9
1 atom ammonia .	2·125
8 atoms water .	9
	20·125

Tartrate. 19. Tartrate of ammonia. The constituents of this salt are

1 atom tartaric acid	8·25
1 atom ammonia .	2·125
	10·375

For 10·375 grains of it and 20·75 grains of nitrate of lead exactly decompose each other.

If the preceding list of ammoniacal salts be sufficiently extensive to entitle us to draw any deductions, we may conclude, that about $\frac{1}{4}$th of the

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ammoniacal salts are destitute of water of crystallization, and that the hydrous salts usually contain only 1 or 2 atoms, and very rarely more than 2 atoms of water in an integrant particle of the salt. Acetate of ammonia, alone, was found to contain 7 atoms, and binoxalate of ammonia 8 atoms.

2. SALTS OF POTASH.

1. Sulphate of potash. This well known salt contains no water, but is composed of Sulphate,

1 atom sulphuric acid	5
1 atom potash . .	6
	11

2. Bisulphate of potash. This salt, which has been long well known, may be easily obtained by dissolving sulphate of potash in dilute sulphuric acid, and evaporating the solution. It crystallizes in thin rhomboids: the plane angles of the larger faces are 97° 20′ and 82° 40′; and the inclinations of the faces to each other are 107° 15′ and 72° 45′. Its taste is acid and bitter, and it is not altered by exposure to the air. A pretty strong heat is necessary to drive off the excess of acid and reduce the salt to the state of simple sulphate of potash. The proportion of the acid and potash to each other, in this salt, has been Bisulphate,

long known;—the following experiment shows us, likewise, the proportion of water:—18·25 grains of it being dissolved in water and mixed with a solution of 26·5 grains of chloride of barium, a double decomposition took place, and after the sulphate of barytes had precipitated the residual liquid was neither affected by sulphate of soda nor muriate of barytes. Hence, the constituents are

2 atoms sulphuric acid	10
1 atom potash . .	6
2 atoms water . .	2·25
	18·25

Nitrate,

3. Nitrate of potash. This salt is seldom free from a little water lodged mechanically between the plates of the crystals, which is easily driven off by drying the salt on the sand bath. Its constituents are

1 atom nitric acid .	6·75
1 atom potash .	6
	12·75

Carbonate,

4. Carbonate of potash. This salt is, in general, stated in chemical books to be incapable of crystallizing: however, I have obtained it in pretty regular prismatic crystals by evaporating its solution in a gentle heat. These crystals are composed of

1 atom carbonic acid	2·75
1 atom potash .	6
2 atoms water .	2·25
	11

The water was determined by heating 11 grains of the crystals to redness: the loss of weight was 2·25 grains.

5. Sesquicarbonate of potash. In a solution of impure carbonate of potash, with which carbonate of ammonia had been mixed and ammonia disengaged, large crystals formed: they were irregular six-sided plates, and seemed composed of a congeries of small crystals, whose form could not be determined. They were translucent, had an alkaline taste, and rendered cudbear paper violet. When analyzed they proved a compound of Sesquicarbonate,

1½ atom carbonic acid	4·125
1 atom potash .	6
6 atoms water .	6·75
	16·875

These crystals were first observed by Dr. Nimmo of Glasgow, a very ingenious chemical friend of mine, who was so good as to bring them to my laboratory, where their composition was determined.

6. Bicarbonate of potash. The constituents of this well known salt are as follows: Bicarbonate,

2 atoms carbonic acid	5·5
1 atom potash .	6
1 atom water .	1·125
	12·625

The crystallized bicarbonate of commerce always contains a little more than an atom of water. This surplus varies in quantity, and is, I suppose, lodged mechanically between the plates of the crystals. The greatest quantity of water which I have met with in this salt is 1½ atom, and the least about 1¼ atom. This uncertainty in the aqueous portion of this salt renders it difficult to employ it in chemical analyses, where an exact quantity of potash is wanted for any particular purpose. But, if we expose the salt to a red heat we convert it into an anhydrous carbonate, composed of

1 atom carbonic acid	2·75
1 atom potash .	6
	8·75

So that 8·75 grains of it contain just 6 grains of potash—in this way I use it.

Phosphate, 7. Phosphate of potash. This salt is not very easily obtained in a state of purity; however, by neutralizing a solution of carbonate of potash with phosphoric acid, concentrating the solution, and setting it aside for some days, a neutral phos-

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phate of potash may be obtained in regular crystals. The taste of this salt is saline and not strong; its crystals are octahedrons, having, most commonly, a short rectangular prism interposed between the two pyramids. It produces no alteration on vegetable blues, and its constituents are

1 atom phosphoric acid	3·5
1 atom potash .	6
1 atom water .	1·125
	10·625

In general, the crystals contain rather more than 1 atom of water. Indeed, in a very careful analysis I obtained exactly 1·68 grain of water from 11·18 grains of the crystals; this is precisely 1½ atom water. I am rather inclined to consider the half atom as chemically combined with the salt likewise; because the crystals may be kept for any length of time in a temperature above 500° without losing any weight. When phosphate of potash is fused it assumes a yellow colour, but becomes again white on cooling.

8. Binarseniate of potash. This salt crystallizes in four-sided prisms, with square bases; but the primary form, according to Mitcherlich, is an octahedron, with a square base. Its constituents are Binarseniate,

2 atoms arsenic acid	15·5
1 atom potash .	6
1 atom water .	1·125
	22·625

But there is almost always a little surplus water (amounting to about half an atom) lodged mechanically between the plates of the crystals.

Chromate, 9. Chromate of potash. This beautiful salt contains no water of crystallization. Its constituents are

1 atom chromic acid	6·5
1 atom potash .	6
	12·5

Bichromate, 10. Bichromate of potash. Neither does this salt, the most splendid and one of the most useful of the whole tribe of salts, contain any water of crystallization. Its constituents are

2 atoms chromic acid	13
1 atom potash .	6
	19

Acetate, 11. Acetate of potash. This salt is so deliquescent that it is not easy to analyze it by the usual methods; but the following experiment comes sufficiently near to leave no doubt about the quantity of water which it contains when in crystals: 29·5 grains of protohydrate of acetic

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acid, equivalent to 25 grains of the pure acid, were saturated with bicarbonate of potash. The quantity necessary for the purpose was 52·74 grains, which I knew, by a previous analysis, to contain exactly 24 grains of potash. Thus I obtained a solution of acetate of potash in water; and I knew the exact weight of the acetic acid, and of the potash constituting the salt. The solution was placed in a small wedgewood dish under the exhausted receiver of an air pump, a few inches above a glass tray, containing concentrated sulphuric acid. In a few days the whole water had evaporated, and left the dry salt, partly in a state of crystals, and partly in that of a dry white crust, which had probably lost a little of its water of crystallization. Its weight was 57·26 grains; and it was obviously composed of

Acetic acid .	25
Potash . .	24
Water . .	8·26
	57·26

If we divide each of these numbers by 4, we shall obtain the atomic weights of the constituents as follows:

Acetic acid	6·25	or	1 atom,
Potash .	6	-	1 atom,
Water .	2·06	-	2 atoms.

There is a slight deficiency in the water, which

I ascribe to the portion of the salt, which had been reduced to a white crust.

Binacetate, 12. Binacetate of potash. This salt was obtained by dissolving carbonate of potash in acetic acid, in the proportion of one integrant particle of the former to two integrant particles of the latter, and concentrating the solution over sulphuric acid, under the exhausted receiver of an air pump. The binacetate crystallized to the very last drop in large transparent flat plates, so irregular, that their form could not be determined, though they were probably four-sided prisms. These crystals had a sour taste, reddened vegetable blues, and deliquesced rapidly when exposed to the air.

25·25 grains of these crystals, when cautiously heated on the sand bath, lost 6·75 grains of their weight, consisting of pure water; and when heated to redness in a platinum crucible, left 8·75 grains of carbonate of potash, equivalent to 6 grains of potash. Hence, the constituents of the salt are

2 atoms acetic acid	12·5
1 atom potash .	6
6 atoms water .	6·75
	25·25

Benzoate, 13. Benzoate of potash. This salt was obtained by digesting benzoic acid and carbonate

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of potash (in the proportion of 15 parts acid and 8·75 carbonate of potash) in water, and concentrating the solution. The crystals obtained were large, transparent flat four-sided rectangular right prisms, terminated by rectangular bases; the lustre silky; the crystals not altered by exposure to the air; taste, a peculiar and not unpleasant sweet. 24·5 grains of these crystals, when burnt in an open crucible, left very nearly 8·75 grains of carbonate of potash. Hence, the constituents of the salt are

1 atom benzoic acid	15
1 atom potash .	6
3 atoms water .	3·375
	24·375

14. Oxalate of potash. This well known salt, which crystallizes in four-sided oblique prisms, is composed of Oxalate,

1 atom oxalic acid	4·5
1 atom potash .	6
1 atom water .	1·125
	11·625

15. Binoxalate of potash. This salt crystallizes in rhombs, only slightly oblique, and therefore approaching the form of cubes. Its constituents are Binoxalate,

2 atoms oxalic acid		9
1 atom potash	.	6
2 atoms water	.	2·25
		17·25

Quadroxalate,

16. Quadroxalate of potash. This salt, for the first knowledge of which we are indebted to Dr. Wollaston, crystallizes in octahedrons, the apexes of which are generally deeply truncated. It is composed of the following constituents:

4 atoms oxalic acid		18
1 atom potash	.	6
7 atoms water	.	7·875
		31·875

Teroxalate,

I once obtained another oxalate of potash, consisting of long prisms, which effloresced when exposed to the air. I found the constituents of this salt in its effloresced state

3 atoms oxalic acid*		13·5
1 atom potash	.	6
6 atoms water	.	6·75
		26·25

But, as this analysis was only made once, and upon a small scale, I lay no great stress upon it. I mention the circumstance to put others on their guard respecting the existence of a fourth

* The analysis gave 3¼th atoms.

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oxalate of potash, if they should happen to meet with these effloresing crystals in any of their experiments.

17. Tartrate of potash. This salt may be obtained in large four-sided prisms, with bases, which are rhombs, with angles of about 93° and 87°. I have obtained it in very large crystals, not less than an inch in diameter. Tartrate.

To determine the quantity of potash which it contains, I exposed 16·5 grains of it to a heat gradually raised to redness, and kept up the red heat in an open platinum crucible till the tartaric acid was completely destroyed. Water was poured into the crucible, and 9 grains of crystals of oxalic acid being added, the crucible was covered with a piece of glass. After the effervescence was at an end, the solution was gently evaporated to dryness, and the dry salt redissolved in water. This solution was perfectly neutral, for it neither altered the colour of litmus nor cudbear paper; but 9 grains of crystals of oxalic acid contain just 4·5 grains of true acid, equivalent to an atom. Hence, 16·5 grains of tartrate of potash contain just 6 grains of potash, equivalent to an atom. This potash must be combined with an atom of tartaric acid, equivalent to 8·25 grains. The remaining 2·25 grains, necessary to make up the weight of tartrate of potash employed, must be water, and is

obviously equivalent to 2 atoms. Thus we see that the crystals of this salt are composed of

1 atom tartaric acid	8·25
1 atom potash .	6
2 atoms water .	2·25
	16·5

The crystals used in the preceding experiment were large and transparent, and had been prepared with great care. I have had in my possession crystals of this salt in needles, which seemed to contain no water of crystallization; for, 14·25 grains of them, being dissolved in water, and mixed with a solution of 20·75 grains of nitrate of lead; the liquid, being examined after the deposition of the tartrate of lead, was found to contain no sensible quantity of tartaric acid, or of oxide of lead, by the tests of tartrate of potash and nitrate of lead.

Bitartrate, 18. Bitartrate of potash. This salt is seldom or never quite free from tartrate of lime. 24·75 grains of it were exposed to a red heat in a platinum crucible; and the residue, being dissolved in water, and mixed with 9 grains of crystallized oxalic acid, was found to be quite neutral. Hence, it is obvious that the constituents of this salt are

2 atoms tartaric acid	16·5
1 atom potash .	6
2 atoms water .	2·25
	24·75

If the salts of potash exhibited above be sufficiently numerous to entitle us to draw any conclusions, we may infer that these salts are either anhydrous, or contain 1, or at most 2 atoms of water. Quadroxalate of potash and sesquicarbonate constitute the only deviations from this law; and from their singular nature, we had reason to look for some peculiarity in their constitution.

3. SALTS OF SODA.

1. Sulphate of soda. This well known salt crystallizes commonly in flat four-sided prisms, the faces of which are channelled longitudinally. It effloresces very speedily when exposed to the air; and loses all its water of crystallization in 24 hours, when confined in the exhausted receiver of an air pump, with sulphuric acid. Its constituents are Sulphate,

1 atom sulphuric acid	5
1 atom soda .	4
10 atoms water .	11·25
	20·25

There is usually a minute quantity of water lodged mechanically between the plates of the crystals. This, in an integrant particle of the salt, may amount at a maximum to 0·03 parts, which constitutes about $\frac{1}{675}$th part of the whole

water in the salt. It amounts to only $\frac{1}{57 \cdot 5}$th of an atom, showing clearly that it is not chemically combined with the salt.

Nitrate, 2. Nitrate of soda. This salt, which crystallizes in rhombs, resembles nitrate of potash in the absence of water of crystallization, and the presence of a small quantity of that liquid lodged mechanically between the plates of the crystals. Its constituents are

1 atom nitric acid	.	6·75
1 atom soda	.	4
		10·75

Carbonate, 3. Carbonate of soda. This salt is familiarly known in this country, being manufactured to a considerable extent. It may be met with in commerce in beautiful crystals, seven or eight inches long; but I have never got it in a state of complete purity. It usually contains about 2 per cent. of sulphate of soda; and it is exceedingly difficult to get rid of this impurity. After 12 careful crystallizations of it in my laboratory, we still could detect the presence of sulphuric acid in the crystals, though in too minute quantity to appreciate its weight. The constituents of this salt, when crystallized in octahedrons, with a rhombic base, the apices of which are always deeply truncated, are as follows:

1 atom carbonic acid		2·75
1 atom soda	.	4
10 atoms water	.	11·25
		18

When the salt is crystallized in hot water, the shape of the crystals is different; and the quantity of water of crystallization is less.

4. Sesquicarbonate of soda. This salt is found native in Barbary, where it is known by the name of trona. It constitutes hard masses, which do not deliquesce in the air; and is said to be employed in the north of Africa, where rain seldom falls, for building the walls of houses. It is manufactured in London, for the use of the soda-water makers; and is sold in the state of a white powder. I have tried to crystallize it, without success. Its constituents are as follows: Sesquicarbonate,

1½ atom carbonic acid		4·125
1 atom soda	.	4
2 atoms water	.	2·25
		10·375

This constitution was first pointed out by Mr. Phillips.

5. Bicarbonate of soda. This salt was made and analyzed many years ago by Rose, and afterwards by Berthollet. I tried to form it in a Nooth's apparatus—the crystallization of the salt Bicarbonate,

speedily plugged up the tubes, and prevented the process from succeeding. I then suspended a concentrated solution of carbonate of soda in a distiller's fermenting tun, till the bicarbonate was deposited in crystals. This process is easy, because the bicarbonate of soda is much less soluble in water than the carbonate. The colour of this salt is white, and the crystals are semi-transparent, and not altered by exposure to the air. They have the shape of four-sided rectangular prisms, terminated by an oblique rectangular base; but were not susceptible of accurate measurement. The taste is alkaline, but exceedingly weak, even when compared with the taste of carbonate of soda. This salt gives a purple colour to cudbear paper, in the same manner as common carbonate of soda. At the temperature of 64°, 100 parts of water dissolve 9·33 parts of this salt. The solution cannot be heated, far less concentrated, without driving off a portion of the acid, and converting the salt first into sesquicarbonate, and finally into common carbonate of soda.

When 10·625 grains of this salt in crystals are fused in a platinum crucible, they lose 3·875 grains of their weight, and leave a residue of anhydrous carbonate of soda, weighing 6·75 grains. 106·25 grains of the crystals dissolved in dilute sulphuric acid with a very violent effervescence; and the loss of weight, owing to the escape of

carbonic acid gas, amounted to 59 grains. This loss is rather too high. The reason was, that the effervescence was so violent, that a little of the liquid was dissipated in drops before I was able to prevent it; but the following experiment, in conjunction with the two preceding ones, leaves no doubt respecting its constituents: 10·625 grains of the crystals were put into a glass jar, water was poured over them, and 9 grains of crystals of oxalic acid added to the liquid. After the effervescence was at an end, the liquid was heated to drive off the whole of the carbonic acid gas. It was then examined, and found perfectly neutral; for it did not in the least alter the colour of cudbear or litmus paper.

From this last experiment we see that 10·625 grains of the crystals contain 4 grains of soda. From the first experiment it appears that, after fusion, these 4 grains of soda still retained 2·75 grains (equivalent to 1 atom) of carbonic acid. Now, $2{\cdot}75 \times 2 = 5{\cdot}5$; and, by the second experiment, the carbonic acid in 10·625 grains of the crystals was 5·9 grains. This exceeds 5·5 a little, for the reason already specified. Thus the constituents of the salt are

2 atoms carbonic acid	5·5
1 atom soda . .	4
1 atom water . .	1·125
	10·625

Borax, 6. Borax. This well known salt has been long in the hands of chemists, and subjected to many analytical experiments; but our processes for separating the boracic acid from the soda are so imperfect, that it was not till after perusing Mr. Arfwedson's new process for analyzing the borates, that I was able to perform a satisfactory analysis. I have shown in a preceding part of this work, that borax is, in reality, a biborate of soda, composed of

2 atoms boracic acid .	6
1 atom soda . .	4
8 atoms water . .	9
	19

Phosphate, 7. Phosphate of soda. This salt, which is the best known of all the phosphates, is much more soluble in hot than in cold water; and, therefore, is easily obtained in regular crystals. The primary form of the crystal is an oblique prism with a rhombic base. The inclinations of the faces of the prism to each other are, according to Mitcherlich's measurement, 67° 50′, and 112° 10′. It effloresces very speedily when exposed to the air; and, on that account, the water of crystallization is not easily determined. The taste of this salt is saline, and not strong. It melts readily when heated; and even the anhydrous salt easily fuses in a red heat.

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I made use of this salt, which is perfectly neutral, to determine the atomic weight of phosphoric acid. After analyzing it in the way described in a preceding part of this work, I formed it by dissolving in water 35 grains of pure phosphoric acid, and adding to the solution 180 grains of crystallized carbonate of soda. The solution, after this addition, was perfectly neutral, and yielded phosphate of soda to the very last drop. Now, 35 grains of phosphoric acid represent 10 atoms, and 180 grains of crystallized carbonate of soda contain 40 grains of soda, equivalent to 10 atoms. This experiment proves decisively, that the atom of phosphoric acid weighs 3·5, and that phosphate of soda is composed of an atom of acid united to an atom of base. The water of crystallization was determined by exposing the salt to a red heat. I have already stated, that when the salt is quite free from efflorescence the water amounts to 12 atoms, for 21 grains of the salt lose 13·5 grains of water. But I have frequently found the water less than this, obviously from an incipient efflorescence. In some of my earlier experiments it amounted only to 11 atoms; but in my later experiments in which I was at the requisite pains to prevent efflorescence, the water was always 12 atoms. The constituents of the salt are

1 atom phosphoric acid	3·5
1 atom soda .	4
12 atoms water .	13·5
	21·0

Biphosphate,

8. Biphosphate of soda. I formed this salt by mixing together solutions of 210 grains of phosphate of soda and 78·75 grains of phosphate of ammonia. The solution was evaporated to dryness, and the dry mass exposed to a red heat to drive off the whole of the ammonia. By this process it is obvious, that the salt contained just 2 atoms of phosphoric acid united to 1 atom of soda. The salt is very difficult to crystallize; it usually concretes into a thick mass when evaporated; it is only by spontaneous evaporation that crystals can be got, and the quantity must be considerable otherwise no crystals can be procured. I did not succeed in procuring crystals in the vacuum of the air pump.

This salt has an acid and saline taste, reddens vegetable blues, and is usually crystallized in four-sided prisms terminated by four-sided pyramids. The inclinations of the faces of the prisms are to each other, according to Mitcherlich's measurement, 78° 30′ and 101° 30′. He considers the primary form to be a rectangular octahedron.

From the method of forming this salt, it is obvious that its constituents are 2 atoms of acid

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and 1 atom of base. 135·5 parts of the salt, when heated to redness, lose, according to Mitcherlich, 35·5 parts of water; this is equivalent to 3½ atoms. Hence, the constituents of the salt are

2 atoms phosphoric acid	7
1 atom soda . .	4
3½ atoms water .	3·9375
	14·9375

It remains to be seen whether the half atom of water be not mechanically lodged between the plates of the crystals.

9. Arseniate of soda. This salt is obtained with great ease in large crystals; because it is much more soluble in hot than in cold water. Mitcherlich has shown that the crystals have the same form as those of phosphate of soda: when exposed to the air the salt speedily effervesces on the surfaces, but does not fall to powder; when heated it undergoes the watery fusion. 100 parts of water at 47° dissolve 22·268 parts of this salt. Arseniate.

I obtained this salt by mixing solutions of 7·75 parts of arsenic acid and 18 of crystallized carbonate of soda. The salt formed was neutral, and the liquid yielded crystals to the very last drop. 20·75 grains of the crystals, when heated, lose 9 grains of water, equivalent to 8 atoms. Hence, the constituents of the salt are obviously

1 atom arsenic acid	7·75
1 atom soda .	4
8 atoms water .	9
	20·75

Binarseniate,

10. Binarseniate of soda. I formed this salt by adding to a solution of 20·75 parts of arseniate of soda, 7·75 parts of arsenic acid. The solution does not crystallize readily; but by perseverance I obtained crystals of the bisalt to the very last drop.

This salt, as Mitcherlich has shown, has the same form with biphosphate of soda. The crystals redden vegetable blues, and do not undergo any visible change from several weeks' exposure to the air; they are exceedingly soluble in water; when heated, they do not, like arseniate of soda, undergo the watery fusion. 25·125 grains of these crystals were exposed to a heat slowly raised to redness: the salt fused into a white enamel, and lost 5·625 grains of its weight. It is obvious from this, and from the method of preparing it, that the constituents of the salt are

2 atoms arsenic acid	15·5
1 atom soda . .	4
5 atoms water . .	5·625
	25·125*

* The analysis of the arseniate of soda, which I published some years ago in the Annals of Philosophy, Vol. XV. p. 82, is very incorrect. I

11. Chromate of soda. This is a beautiful transparent yellow salt, one of the finest of the chromates. Its crystals are four-sided transparent prisms, with square bases—sometimes octahedrons, usually elongated. It does not seem to undergo any alteration by exposure to the air, but melts when exposed to a very moderate heat. Its constituents are as follows: Chromate,

1 atom chromic acid	6·5
1 atom soda . .	4
12 atoms water .	13·5
	24

12. The bichromate is a very dark red salt with a shade of brown; it crystallizes in large irregular plates, seemingly rhombic. I have not yet succeeded in getting it quite free from chromate, for the solubility of both salts is nearly the same. Bichromate,

13. Tungstate of soda. I have obtained this salt both in six-sided prisms, apparently regular, and in four-sided oblique prisms. Its taste is intensely bitter. Its constituents are as follows: Tungstate,

was not aware at the time, that neither the quantity of arsenic acid nor phosphoric acid can be accurately determined by precipitation. The method of determining these salts, which I have given in the text, was by synthesis—a method susceptible of the most perfect accuracy, if the requisite care be taken to employ the constituents in a state of purity.

1 atom tungstic acid	18·75
1 atom soda	4
6 atoms water	6·75
	29·5

Columbate, 14. Columbate of soda. The appearance and properties of this salt have been described in Vol. II. p. 78. of this work. Its constituents are as follows:

1 atom columbic acid	19
1 atom soda .	4
10 atoms water .	11·25
	34·25

Acetate, 15. Acetate of soda. This salt is the best known of all the alkaline acetates. It is not altered by exposure to the air, and is capable of bearing a higher temperature without decomposition than any of the other acetates which I have examined. The constituents of this salt are as follows:

1 atom acetic acid	6·25
1 atom soda	4
6 atoms water	6·75
	17

Succinate, 16. Succinate of soda. This salt crystallizes in four-sided prisms, and its constituents are as follows:

1 atom succinic acid	6·25
1 atom soda	4
6 atoms water	6·75
	17

so that it resembles the acetate of soda exactly in its constitution.

17. Oxalate of soda. I have never been able to obtain this salt in regular crystals. It usually forms white opaque crusts; once I got it in small round globules rather beautiful, and probably composed of small prisms diverging from a centre; it contains no water of crystallization; but the integrant particle of the salt, dried in the open air, usually contains about ¼th of an atom of water, lodged mechanically between the fibres of the mass. Its constituents (when this water is driven off by a moderate heat) are Oxalate,

1 atom oxalic acid	4·5
1 atom soda	4
	8·5

18. Binoxalate of soda. This salt is easily formed by digesting a solution of 9 parts of oxalic acid crystals on 9·5 parts of oxalate of soda. A complete solution takes place, and when the solution is concentrated it readily deposites fine crystals of binoxalate of soda, which have the form of flat rectangular prisms, the larger faces of which consist of rhomboids with angles of Binoxalate,

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nearly 120° and 60°—not altered by exposure to the air—taste very sour, and it reddens vegetable blues powerfully. At the temperature of 46°, 100 parts of water dissolve 1·88 of these crystals. At the temperature of 83°, the quantity of crystals dissolved by 100 water is 3·49—specific gravity of the crystals 1·980. 16·375 grains of these crystals, heated on the sand bath, lost 3·375 grains of weight; hence, the constituents are

2 atoms oxalic acid	9
1 atom soda	4
3 atoms water	3·375
	16·375

Tartrate,

19. Tartrate of soda. This salt crystallizes in fine needles having considerable lustre. Its constituents are

1 atom tartaric acid	8·25
1 atom soda	4
2 atoms water	2·25
	14·5

To a solution of this salt in water, we added the requisite quantity of tartaric acid to convert the whole into a bitartrate, in order to verify Thenard's statement, that there exists a bitartrate of soda nearly as insoluble as bitartrate of potash;*

* Ann. de Chim. XXVIII. 12.

but we could not succeed in obtaining any such salt.

20. Saclactate of soda. This salt has been noticed in a preceding chapter. Its constituents are Saclactate.

1 atom saclactic acid	13
1 atom soda	4
5 atoms water	5·625
	22·625

21. Urate of soda. This salt was formed by digesting together uric acid, and a solution of the carbonate of soda in the requisite proportions. The whole acid dissolved in the hot liquid, but afterwards precipitated when the solution was set aside; it was dried in the open air. This salt is a white tasteless powder, not sensibly soluble in water. Its constituents are Urate.

1 atom uric acid	9
1 atom soda	4
1 atom water	1·125
	14·125

The salts of soda, in general, present a striking contrast to those of potash: only two of them are anhydrous—the nitrate and oxalate; the urate contains only 1 atom of water, and the sesquicarbonate and tartrate only 2; all the rest contain 5, 6, 8, 10, or 12 atoms of water.

No other genus of salts, except those of soda, contains 12 atoms of water.

4. SALTS OF BARYTES.

Sulphate, 1. Sulphate of barytes. This well known salt contains no water of crystallization; though the native crystals decrepitate, and probably, therefore, contain a little water mechanically lodged between their plates. I find that precipitated sulphate of barytes, if it be well washed, and thoroughly dried by exposure to the air for a sufficient time, retains about 3 per cent. of water, which is easily driven off by exposing the powder to a red heat in a platinum crucible. This amounts to rather more than the third of an atom of water which is only mechanically lodged in the pores of the powder, and not chemically combined with it. The constituents of the salt are

1 atom sulphuric acid	5
1 atom barytes	9·75
	14·75

Nitrate, 2. Nitrate of barytes. This salt usually crystallizes in octahedrons; it is not altered by exposure to the air; it is apt to be contaminated with muriate of barytes, and then contains

water; but the pure nitrate of barytes is anhydrous, being composed of

1 atom nitric acid	6·75
1 atom barytes	9·75
	16·5

From the analyses of this salt by Kirwan, and Fourcroy, and Vauquelin, and also from the method which Dr. Forchhammer took to obtain manganesic acid—namely, heating black oxide of manganese and nitrate of barytes, (the success of which, he says, depends upon not driving off the water of crystallization of the salt)—there is reason to suspect that nitrate of barytes sometimes contains water of crystallization; but I have never myself seen the salt in that state.

3. Carbonate of barytes. This salt is also well known. It is anhydrous, and composed of Carbonate,

1 atom carbonic acid	2·75
1 atom barytes	9·75
	12·5

4. Phosphate of barytes. This is a tasteless white powder, insoluble in water, and therefore not capable of being obtained in the state of crystals. It is anhydrous, and composed of Phosphate,

1 atom phosphoric acid	3·5
1 atom barytes	9·75
	13·25

Biphosphate,

5. Biphosphate of barytes. This salt, first noticed by Berzelius, crystallizes in four-sided rectangular prisms with square bases. I have not analyzed it; but from the experiments of Berzelius, I consider it as a compound of

2 atoms phosphoric acid	7
1 atom barytes . .	9·75
2 atoms water . .	2·25
	19

Chromate,

6. Chromate of barytes. This is a pale yellow powder, without either beauty or intensity of colour. It is tasteless and anhydrous, and is composed of

1 atom chromic acid	6·5
1 atom barytes	9·75
	16·25

I have not made any attempts to prepare a bichromate of barytes.

Sesquicolumbate,

7. Sesquicolumbate of barytes. This is a tasteless white powder, composed of

1½ atom columbic acid	28·5
1 atom barytes	9·75
	38·25

Acetate,

8. Acetate of barytes. This salt usually crystallizes in long needles, so very slender that it

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is difficult to make out the form. Its constituents are

1 atom acetic acid	6·25
1 atom barytes	9·75
3 atoms water	3·375
	19·375

It is not sensibly altered by exposure to the air, at least in my laboratory which is rather damp.

9. Oxalate of barytes is a white tasteless powder, obtained when oxalate of ammonia and nitrate or muriate of barytes are mixed in the atomic proportions. It is not sensibly soluble in water, and does not affect vegetable blues. When 17·625 grains of it are exposed to a red heat in a platinum crucible, there remain 12·5 grains of carbonate of barytes, equivalent to 9·75 grains of barytes. Hence, the constituents of the salt are Oxalate,

1 atom oxalic acid	4·5
1 atom barytes	9·75
3 atoms water	3·375
	17·625

10. Binoxalate of barytes was formed by decomposing the muriate of barytes, and digesting the precipitate with twice the atomic quantity of oxalic acid requisite to saturate the base. It crystallizes in needles so irregular that their shape could not be determined; it has but little Binoxalate,

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taste, is very sparingly soluble in water, but strongly reddens vegetable blues. 22·175 grains of this salt when heated to redness in a platinum crucible, left 12·5 grains of carbonate of barytes. Hence, the constituents are

2 atoms oxalic acid	9
1 atom barytes	9·75
3 atoms water	3·375
	22·125

Tartrate. 11. Tartrate of barytes forms irregular crystalline grains; it is tasteless, and does not alter the colour of vegetable blues. It loses no weight unless it be exposed to a heat sufficiently high to decompose the acid. 18 grains of the salt in powder, kept in a red heat till it had become white, were reduced to 12·5 grains, which were carbonate of barytes. Hence, the salt is anhydrous, and composed of

1 atom tartaric acid	8·25
1 atom barytes	9·75
	18

Bitartrate. 12. Bitartrate of barytes forms transparent crystals in the form of right prisms with bases apparently square. Taste acid, and reddens vegetable blues slowly, on account of its little solubility. 100 parts of water, at the temperature of 65°, dissolve 1·24 parts of this salt. Its con-

stituents, determined both analytically and synthetically, were

2 atoms acid	16·5
1 atom base	9·75
2 atoms water	2·25
	28·5

From the preceding catalogue it appears that a considerable proportion of the salts of barytes are anhydrous. Indeed, it would have been easy to have added to the list of anhydrous barytes salts, if I had not been anxious to confine myself to those which I have myself examined. For the arseniate, tungstate, molybdate, seleniate, and sulphite of barytes are all anhydrous. So also is the borate, which I believe to be a compound of

1 atom boracic acid	3
1 atom barytes	9·75
	12·75

Those barytes salts which contain water seem never to have more than 1, 2, or at most 3 atoms of that liquid; so that barytes in this respect agrees with ammonia and potash.

5. SALTS OF STRONTIAN.

1. Sulphate. This salt, like the sulphate of barytes, contains no water of crystallization; Sulphate,

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even the precipitated salt is perfectly anhydrous, if it be dried in a temperature of 212°. Its constituents are

1 atom sulphuric acid	5
1 atom strontian	6·5
	11·5

When the precipitated sulphate of strontian is dried in the open air, it retains about $\frac{1}{144}$th part of its weight of water mechanically lodged among its particles. This amounts to about $\frac{1}{8}$th of an atom.

Nitrate, 2. Nitrate of strontian. Of this salt there are two species, distinguished from each other by the presence or absence of water of crystallization.

Anhydrous; (1.) Anhydrous nitrate of strontian crystallizes in dodecahedrons composed of two six-sided pyramids applied base to base. The apices of the pyramids are deeply truncated, so as to give the crystal the appearance of a six-sided table with bevilled edges; it is not altered by exposure to the air. Its constituents are

1 atom nitric acid	6·75
1 atom strontian	6·5
	13·25

Hydrous. (2.) Hydrous nitrate of strontian is a transparent salt, crystallized in acute rhomboids. Its

lustre is glassy, and it effloresces when exposed to the air. Its constituents are

1 atom nitric acid	6·75
1 atom strontian	6·5
4 atoms water	4·5
	17·75

3. Carbonate of strontian. This salt, like the carbonate of barytes, is anhydrous; the water contained in the native carbonate amounts certainly to less than $\frac{1}{1000}$th part of the whole. The constituents of the pure carbonate are Carbonate.

1 atom carbonic acid	2·75
1 atom strontian	6·5
	9·25

The carbonate of strontian, from Strontian in Argyleshire, contains rather more than 6 per cent. of carbonate of lime; or it is a compound of very nearly

10 atoms carbonate of strontian	92·5
1 atom carbonate of lime	6·25
	98·75

Whether this mineral be a chemical compound, or only a mixture, I cannot say; but, from its appearance, one would be disposed to believe that the two carbonates are in chemical union.

This mineral, it is well known, has a fine green colour. The only metallic bodies which I can find in it are, protoxide of manganese, which is green, and perhaps a trace of iron. Is it probable that the green colour is furnished by the protoxide of manganese?

Phosphate, 4. Phosphate of strontian. This salt is easily obtained by mixing together solutions of phosphate of soda and nitrate of strontian in the atomic proportions. The phosphate of strontian precipitates in the state of a white powder, which must be edulcorated, and dried in the open air. The phosphate of strontian is a fine white light powder, having scarcely any taste, and producing no change on vegetable blues.

When exposed to the greatest temperature of the sand bath (about 600°), it loses no weight. 10 grains of it, when exposed to a red heat, lose 0·84 grain of weight, consisting of water driven off. Hence, 11·125 grains of the salt would have lost 0·9345 grain. This approaches so nearly to 1 atom of water, that I consider the composition of the salt to be

1 atom phosphoric acid	3·5
1 atom strontian .	6·5
1 atom water .	1·125
	11·125

Biphosphate, 5. Biphosphate of strontian. This salt was

formed by dissolving phosphate of strontian in phosphoric acid, and mixing the solution with alcohol. The biphosphate precipitated in the state of a fine white soft powder, which had an acid taste, and strongly reddened vegetable blues. 15·75 grains of this salt, dried in the open air, lost, when exposed to an incipient red heat, 2·25 grains of water. From this it is obvious that the constituents of the salt are

2 atoms phosphoric acid	7
1 atom strontian .	6·5
2 atoms water .	2·25
	15·75

When the alcoholic solution, from which the biphosphate of strontian had precipitated, was concentrated and set aside, it deposited a number of transparent crystals, which had a very acid taste, and consisted of phosphoric acid and strontian. The result of an analysis of them led me to consider these crystals as a quadrophosphate of strontian; but the quantity which I possessed was too small to enable me to determine the point in a satisfactory manner.

6. Arseniate of strontian. This salt was obtained by mixing together solutions of nitrate of strontian and arseniate of soda in the atomic proportions. No immediate precipitate appeared; but in 24 hours a number of small crystals were Arseniate,

deposited on the sides of the vessel. These crystals proved, on examination, to be arseniate of strontian. They were very minute rectangular four-sided prisms, having no taste, and producing no change on vegetable blues. The salt dissolves very sparingly in water—100 grains of that liquid, at the temperature of 60°, dissolving only 0·284 grain of the crystals. When 23·25 grains of these crystals were exposed to a heat gradually raised to redness, the loss of weight, owing to the escape of moisture, was 9 grains. Hence, the constituents of the salt are

1 atom arsenic acid	7·75
1 atom strontian .	6·5
8 atoms water .	9·0
	23·25

Chromate. 7. Chromate of strontian. This salt is easily formed by mixing together solutions of chromate of potash and nitrate of strontian—the chromate of strontian immediately falls down. When edulcorated and dried in the open air, it is a powder, having a fine yellow colour, destitute of taste, and not sensibly soluble in water. It loses no weight by exposure to a red heat, and is, therefore, anhydrous. Its constituents are

1 atom chromic acid	6·5
1 atom strontian .	6·5
	13

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8. Acetate of strontian crystallizes in thin flat transparent plates; but, by spontaneous evaporation, it may be obtained in long quadrangular prisms with rectangular bases. Its taste is sharp, and it gives an impression of bitterness. The salt does not affect vegetable blues. It has a silky lustre, is pretty soluble in water, and is not altered by exposure to the atmosphere. 13·875 grains of this salt were exposed to a red heat in a platinum crucible; the residual matter was digested in a solution of carbonate of ammonia till the whole liquid was driven off. It was then exposed to a heat sufficient to expel the whole ammonia. The carbonate of strontian thus obtained weighed 9·25 grains, equivalent to 6·5 grains of strontian. Hence, the constituents of the salt are Acetate.

1 atom acetic acid	6·25
1 atom strontian .	6·50
1 atom water .	1·125
	13·875

9. Oxalate of strontian is a white tasteless insoluble powder, obtained by mixing oxalate of ammonia and muriate of strontian together, in the atomic proportions. 13·25 grains of this salt, dried in the open air upon paper, were exposed to a red heat in a platinum crucible. The carbonate of strontian remaining weighed 9·25 Oxalate.

grains, equivalent to 6·5 grains of strontian. Hence, the constituents of the salt are

1 atom oxalic acid .	4·5
1 atom strontian .	6·5
2 atoms water .	2·25
	13·25

Binoxalate, 10. Binoxalate of strontian was formed by employing twice the requisite quantity of oxalic acid to saturate the strontian. It crystallizes in pretty large four-sided prisms, too rough on the surface to admit of measuring the angles; feels harsh, reddens vegetable blues, but dissolves very sparingly in water. 15·5 grains of the salt, heated to redness, left 9·25 of carbonate of strontian. Hence, the salt is anhydrous, and composed of

2 atoms oxalic acid .	9
1 atom strontian .	6·5
	15·5

Tartrate, 11. Tartrate of strontian. This salt was obtained by mixing tartrate of potash and nitrate of strontian in the atomic proportions, each in pretty concentrated solutions. The tartrate of strontian was gradually deposited in oblique rhomboids, with angles of 113° 20′, and 66° 40′. This salt is tasteless, and insoluble in water. It was analyzed by exposing 18·125 grains of it to redness in an open platinum crucible, and keep-

ing up the heat till the carbonate of strontian became white. It weighed 9·25 grains. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom strontian .	6·5
3 atoms water .	3·375
	18·125

The salts of strontian resemble those of barytes, though there is a tendency in these salts to contain more water. Six of the salts described above, or one half of the whole, are anhydrous; two contain 1 atom water; and we have a single salt with 2, 3, 4, and 8 atoms of water respectively.

6. SALTS OF LIME.

1. Sulphate of lime. Of this salt there are two species, both found native; namely, the anhydrous and hydrous. Sulphate,

(1.) Anhydrous sulphate of lime, distinguished by mineralogists by the name of *anhydrite*, crystallizes in right rectangular prisms. Its constituents are Anhydrous;

1 atom sulphuric acid	5
1 atom lime . .	3·5
	8·5

Hydrous.

(2.) Hydrous sulphate of lime, long familiar to chemists and mineralogists under the names of gypsum and selenite, crystallizes in right oblique angled prisms; and, when formed artificially, it crystallizes in small silky needles, so minute, that their shape is not easily determined. The constituents of this salt are

1 atom acid	.	5
1 atom lime	.	3·5
2 atoms water	.	2·25
		10·75

The water of crystallization may be driven off by a temperature not exceeding 500°. In a red heat, some of the sulphuric acid is driven off; and, if water be poured on the salt thus treated, it will be found to give a violet colour to cudbear paper. This circumstance long perplexed me in the analyses of minerals, when I was searching for an alkali. The liquid containing the supposed alkali was filtered, evaporated to dryness, and water digested upon the residual matter. This water, by giving a violet colour to cudbear paper, gave an indication of an alkali; but the most careful examination of what the water had dissolved frequently discovered nothing but lime. I found at last, that all the filtering paper which I could procure contained sulphate of lime; a little of this was dissolved

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by the liquid which passed through the filter—hence the appearances. The presence of sulphate of lime in the filters is a very great annoyance, and stands a good deal in the way of accurate analyses. I diminish the evil, but do not remove it completely, by washing the filter, first in dilute nitric or muriatic acid, and then in water.

2. Nitrate of lime. This salt is exceedingly soluble in water, and very difficult to procure in regular crystals. But it is easy, by concentrating the solution sufficiently and then setting it aside in a cool place, to obtain the salt in the state of a beautiful fibrous white mass, not unlike mesolite. In this state it is composed of Nitrate,

1 atom nitric acid	6·75
1 atom lime . .	3·5
3 atoms water .	3·375
	13·625

When a solution of this salt is put under the exhausted receiver of an air pump along with sulphuric acid, it becomes a thick syrup, which, on the least agitation, concretes into a white solid mass, with the evolution of a good deal of heat. In this state it consists of

1 atom nitric acid .	6·75
1 atom lime .	3·5
6 atoms water .	6·75
	17

The water actually present in our analysis of this mass exceeded 6 atoms by rather less than half an atom. Had the action of the acid continued for a little longer, we should probably have obtained the exact atomic quantity contained in the preceding table. The small surplus water was doubtless lodged mechanically in the pores of the dry mass.

Carbonate, 3. Carbonate of lime. This well known mineral, when pure, is anhydrous. It may, indeed, contain a little water lodged mechanically between the plates of the crystals; but such, when it exists, is very small, and is easily driven off by exposing the salt to a moderate heat. Its constituents are

1 atom carbonic acid	2·75
1 atom lime	3·5
	6·25

When carbonate of lime is rendered soluble in water by means of carbonic acid gas, a bicarbonate is formed, which seems only capable of existing in solution,—at least, I have never succeeded in obtaining it in a concrete state. Perhaps if it were crystallized under great compression this bicarbonate might be obtained.

Phosphate, 4. Phosphate of lime. This salt can only be formed artificially in the state of a white powder. It is neutral, insoluble, and anhydrous, being composed of

1 atom phosphoric acid	3·5
1 atom lime . .	3·5
	7

5. Arseniate of lime. This salt may be formed by dropping arsenic acid into lime water. It is a white anhydrous tasteless powder, composed of Arseniate,

1 atom arsenic acid	7·75
1 atom lime . .	3·5
	11·25

There is, likewise, a binarseniate of lime which crystallizes; but I have not subjected it to analysis.

6. Chromate of lime. This is rather a fine yellow powder, which is insoluble in water and anhydrous,—it would probably answer as a pigment. Its constituents are Chromate,

1 atom chromic acid	6·5
1 atom lime . .	3·5
	10

7. Tungstate of lime. This salt, which is occasionally met with in native octahedral crystals, is likewise anhydrous, and is undoubtedly a compound of Tungstate,

1 atom tungstic acid	18·75
1 atom lime	3·5
	22·25

Acetate, 8. Acetate of lime. When a solution of this salt is kept for some time in vacuo over sulphuric acid, it is gradually converted into a mamillated mass, which, internally, has a silky lustre, and somewhat the appearance of asbestus. 16·5 grains of the salt, in this state, give 6·25 grains of carbonate of lime. Hence, the constituents of acetate of lime are

1 atom acetic acid	6·25
1 atom lime . .	3·5
6 atoms water .	6·75
	16·5

Oxalate, 9. Oxalate of lime. This salt is a white heavy tasteless powder, quite insoluble in water. When dried in the open air its constituents are

1 atom oxalic acid	4·5
1 atom lime . .	3·5
2 atoms water .	2·25
	10·25

It requires exposure to a heat rather above 500° to drive off the water from this salt.

Tartrate, 10. Tartrate of lime. This is also a white tasteless insoluble powder. When dried in the open air its constituents are

1 atom tartaric acid	8·25
1 atom lime . .	3·5
4 atoms water .	4·5
	16·25

It is scarcely possible to drive off the whole water, without affecting the acid, which is much more easily decomposed than either acetic or oxalic acid. It was analyzed by keeping 16·25 grains of it in a low red heat till the carbonate of lime became white. It weighed 6·25 grains very nearly.

From the preceding list it appears, that many of the salts of lime are anhydrous. The water of crystallization, when it exists, amounts to 2, 3, 4, or 6 atoms. No salt of lime is known which contains more than 6 atoms.

7. SALTS OF MAGNESIA.

1. Sulphate of magnesia. This well known salt crystallizes in right square prisms, and is not altered by exposure to the air. Its constituents are Sulphate,

1 atom sulphuric acid	5
1 atom magnesia	2·5
7 atoms water .	7·875
	15·375

2. Nitrate of magnesia, though it crystallizes readily enough, is so deliquescent a salt that it is very difficult to obtain it in a state proper for analysis. 16 grains of the crystals, dried by pressure between folds of blotting paper, were Nitrate,

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heated in a platinum crucible till every thing was expelled except the base: the residual magnesia weighed 2·5 grains. Hence, the salt is a compound of

1 atom nitric acid	6·75
1 atom magnesia .	2·5
6 atoms water .	6·75
	16

Carbonate, 3. Carbonate of magnesia. This salt occurs native in great abundance in Hindostan, where it constitutes a range of rocks extending a considerable way.* Its colour is snow white, and its specific gravity 2·7374; it is rather harder than fluor spar, and it dissolves very slowly in acids, unless it be reduced to powder, and the action of the acid promoted by heat. I found the constituents of a very good specimen of this mineral as follows:

Carbonic acid .	51·627
Magnesia .	47 566
Deutoxide of manganese	0·807
	100

Stromeyer analyzed a specimen of the same mineral from Baumgarten in Silesia. Its constituents were

* For the specimen which I subjected to analysis I was indebted to the friendship of Mr. Babington of London.

Carbonic acid .	50·7512
Magnesia . .	47·6384
Deutoxide of manganese	0·2117
Water . . .	1·4037
	100*

The salt is obviously anhydrous, and composed of

1 atom carbonic acid	2·75	or	53·411
1 atom magnesia .	2·5	-	45·782
	5·25		

It would appear from comparing the constituents of the neutral salt with those of the native anhydrous carbonate, that in the native rock a little of the acid has been dissipated. My specimen was from the surface of the rock. No doubt the same was the case with the specimen analyzed by Stromeyer. It would be interesting to know whether specimens from the interior parts of the rock would be found to contain their full complement of carbonic acid.

It is obvious from Berzelius' analysis, that the artificial carbonate of magnesia (obtained by exposing a solution of magnesia in carbonic acid to spontaneous crystallization) is a compound of

* Untersuchungen, p. 120.

1 atom carbonic acid	2·75
1 atom magnesia	2·5
3 atoms water	3·375
	8·625 *

I find that this artificial carbonate becomes anhydrous by simple exposure to the air, and falls down into powder.

Hydrate, 4. Hydrate of magnesia. This beautiful mineral is obviously analogous to a salt. It was first discovered by Dr. Bruce in the serpentine at Hoboken in New Jersey; more lately, magnificent specimens have been detected in the Shetland Islands by Dr. Hibbert—I believe, in the serpentine of the island of Unst. It has a beautiful snow white colour, sometimes with a shade of green; a pearly lustre; is composed of thin semitransparent folia, and has a specific gravity of 2·13. Its constituents, according to the analysis of Stromeyer which I repeated with scarcely any difference in the result, are

1 atom water . .	1·125
1 atom magnesia . .	2·5
Water	0·00546
Oxides of iron and manganese	0·00762

The small excess of water was probably combined with the oxides of iron and manganese present in the mineral. The whole of the fo-

* Afhandlingar, VI. 21.

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reign matter amounts only to $\frac{1}{280}$th of the mineral.

5. Magnesia alba of the shops. It is obvious, from the analysis of this powder by different chemists, that its composition varies considerably. Berzelius has shown that the composition is regulated by the quantity of water employed, and by the temperature: for the powder is obtained by precipitating the sulphate and muriate of magnesia by an alkaline carbonate. Berzelius analyzed a portion of it washed in boiling water, till the liquid ceased to dissolve any more. He found it a compound of Magnesia alba.

Magnesia	44·58	or	3·434
Carbonic acid	35·70	-	2·75
Water	19·72	-	1·519
	100·00		

This approaches

1 atom carbonic acid	2·75
$1\frac{1}{2}$ atom magnesia	3·75
$1\frac{1}{2}$ atom water	1·6875

But Berzelius considers it as a compound of 3 atoms carbonate of magnesia and of 1 atom of quadrohydrate—

3 atoms carbonate of magnesia	15·75
1 atom quadrohydrate	7
	22·75 *

* Afhandlingar, VI. 24.

The constituents per cent. according to this view of the subject, would be

Carbonic acid	36·263
Magnesia	43·956
Water	19·781
	100·000

numbers which approach sufficiently near the result of the analysis to give much probability to the opinion.

Biborate, 6. Borate of magnesia. The mineral called boracite, which crystallizes in cubes, having their alternate angles truncated, and which has a specific gravity of 2·566, is a compound of boracic acid and magnesia, and from the best analyses of it hitherto made, it seems to be a biborate of magnesia, composed of

2 atoms boracic acid	6
1 atom magnesia	2·5
	8·5

It is destitute of water.

Phosphate, 7. Phosphate of magnesia. When this salt is obtained by mixing together solutions of sulphate of magnesia and phosphate of soda, it crystallizes in small flat four-sided prisms, having a silky lustre, and destitute of taste. It is composed of

1 atom phosphoric acid	3·5
1 atom magnesia	2·5
7 atoms water	7·875
	13·875

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8. Arseniate of magnesia may be prepared by mixing together rather diluted solutions of sulphate of magnesia and arseniate of soda in the atomic proportions. Little immediate change is produced, but a portion of arseniate of magnesia gradually precipitates in a fine white loose state, very similar in appearance to native hydrate of magnesia. When the mixture is set aside for twenty-four hours, a number of crystals of arseniate of magnesia make their appearance in it. They are small transparent four-sided flat prisms, with very oblique terminations; they constitute tufts of crystals, radiating from a centre, and are formed in the portion of the salt which has the form of a powder. These crystals, when dry, are transparent and tasteless. They are slightly soluble in water—though that liquid after being saturated with the salt in a boiling heat, has no perceptible taste, and 1000 parts of boiling water dissolve only 1·5 parts of these crystals. 19·25 grains of these crystals, when exposed on the sand bath to a heat of about 500°, lose 6·75 grains of weight, and when exposed to a low red heat the loss amounts to 9 grains. As these crystals have no action on vegetable blues, they are evidently neutral: hence, the constituents are Arseniate,

1 atom arsenic acid	7·75
1 atom magnesia	2·5
8 atoms water	9·0
	19·25

At the temperature of about 500° they part with 6 atoms water, but still retain 2 atoms which are disengaged in a red heat.

Chromate, 9. Chromate of magnesia. This is a fine transparent yellow coloured salt, which crystallizes in flat rhomboids, the obtuse angles of which are usually truncated. It is very soluble in water; its constituents are as follows:

1 atom chromic acid	6·5
1 atom magnesia	2·5
2 atoms water	2·25
	11·25

When this salt is exposed to a strong red heat it is partially decomposed; for it is no longer completely soluble in water.

Acetate, 10. Acetate of magnesia. A neutral solution of this salt was left in vacuo over sulphuric acid. It gradually inspissated into a thick transparent jelly, which was exposed for some time to the heat of the sand bath. Being laid in a cool place it became solid on the surface, but remained liquid below. Being stirred with a glass rod, the whole concreted into a white opaque crystalline looking mass, not unlike loaf sugar; it did not deliquesce, though left for a week in an open vessel. The taste of this salt is hot and bitter; at first it gives a slight impression of acetic acid which soon passes off, leaving a very disagreeable taste behind.

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14·375 grains of this salt were kept in a red heat till nothing remained but pure magnesia, which weighed 2·5 grains. As the salt was neutral, its constituents are obviously

1 atom acetic acid	6·25
1 atom magnesia	2·50
5 atoms water	5·625
	14·375

11. Oxalate of magnesia is a tasteless salt, which can only be obtained in the state of a white powder. To determine its composition I took 9·25 grains of the salt in a state in which it did not alter the colour of vegetable blues, and exposed them to a strong red heat in a platinum crucible; there remained behind 2·5 grains of pure magnesia. This being equivalent to an atom of magnesia, it is obvious that the oxalic acid in the salt amounted to 4·5, or an atom. Hence, the constituents of oxalate of magnesia are Oxalate,

1 atom oxalic acid	4·5
1 atom magnesia	2·5
2 atoms water	2·25
	9·25

If the oxalate of magnesia be dried by means of artificial heat, the water contained in it is always less than two atoms.

12. Binoxalate of magnesia. This salt may Binoxalate,

be obtained by mixing together solutions of binoxalate of potash and sulphate of magnesia in the atomic proportions. No immediate precipitate falls; but when the liquid is concentrated, crystals of binoxalate of magnesia are gradually deposited. They have the form of pretty large flat rectangular four-sided prisms. The taste of this salt is acid, and it strongly reddens vegetable blues. It does not dissolve completely in water; but when digested in that liquid, a considerable portion of the oxalic acid and some of the magnesia is washed off, and an insoluble oxalate of magnesia remains behind. When heated, oxalic acid readily sublimes. 19·375 grains of this salt were digested in water till the liquid would take up no more; the undissolved oxalate of magnesia weighed 5·054 grains, and contained 2·469 grains of oxalic acid. The dissolved portion of the salt was mixed with muriate of lime. The oxalate of lime precipitated weighed, after being washed and dried in a heat of 83°, 14·489 grains, equivalent to 6·361 grains of oxalic acid. Thus the oxalic acid contained in 19·375 grains of the salt, amounted to 8·83 grains, or very nearly 2 atoms. 19·375 grains of the salt were exposed to a strong red heat in a platinum crucible, the magnesia remaining weighed 2·69 grains. But it effervesced for a little with nitric acid, and therefore was not quite free from car-

bonic acid. From these experiments I consider the constituents of the salt to be

2 atoms oxalic acid	9
1 atom magnesia	2·5
7 atoms water	7·875
	19·375

13. Tartrate of magnesia. This salt, which is a white tasteless powder, is composed of Tartrate.

1 atom tartaric acid	8·25
1 atom magnesia	2·5
2 atoms water	2·25
	13

14. Bitartrate of magnesia. This salt was formed by dissolving tartrate of magnesia in tartaric acid and crystallizing the solution. The bitartrate is deposited in small acicular crystals; it has a slightly acid taste, and reddens vegetable blues. 20·125 grains of these crystals were kept in a red heat till nothing remained but the magnesia, which weighed 2·5 grains. Hence, the salt is composed of Bitartrate.

2 atoms tartaric acid	16·5
1 atom magnesia	2·5
1 atom water	1·125
	20·125

The water of crystallization in the salts of mag-

nesia varies more in the different species, than in any of the preceding genera of salts. Two of the species are anhydrous—three contain 1 atom of water—three contain 2 atoms—one contains 3—one 5—one 6—two contain 7, and one contains 8 atoms.

8. SALTS OF ALUMINA.

Sulphate,

1. Sulphate of alumina. This salt does not crystallize regularly; but if we digest dilute sulphuric acid over hydrate of alumina for two or three days, and set the solution aside after having concentrated it sufficiently, it gradually congeals into a beautiful, white, soft, light, semi-transparent mass, which may be dried upon blotting paper, and is not altered by exposure to the air. It always reddens vegetable blues how long soever the liquid be digested over the alumina; I continued the digestion for a month without altering this property. All the salts of alumina, so far as I have tried them, redden vegetable blues. Sulphate of alumina is composed of

1 atom sulphuric acid	5
1 atom alumina	2·25
7 atoms water	7·875
	15·125

This salt is capable of congealing though it contains a slight excess of acid. I have obtained it composed of

Sulphuric acid	5·625
Alumina	2·25
Water	7·875
	15·75

The excess was just the $\frac{1}{8}$th of an atom of sulphuric acid. To prevent any such excess we must continue the digestion over alumina for a considerable time; for the action of the acid, when nearly saturated, becomes very feeble.

2. Trisulphate of alumina. This is a fine white aluminous looking mineral, found in Sussex and in other places, and distinguished among mineralogists by the name of *aluminite*. Its constituents, as appears from the analysis of Stromeyer, are Trisulphate,

1 atom sulphuric acid	5
3 atoms alumina	6·75
9 atoms water	10·125
	21·875

I have already noticed disulphate of alumina in a preceding chapter.

3. Dinitrate of alumina. This salt was obtained by digesting hydrate of alumina in dilute nitric acid till the acid refused to dissolve any more of the hydrate; the liquid was then con- Dinitrate,

centrated and set aside. It concreted into a white solid matter, which was dried by pressure between folds of blotting paper. Thus prepared, it was a fine white crystalline powder exceedingly soluble in water, and reddening vegetable blues. Its taste was astringent and sweet, with an impression of acidity. This salt was analyzed in the following manner:

22·5 grains of it were exposed to a red heat, and kept at that temperature till nothing remained but the alumina, which weighed exactly 4·5 grains.

22·5 grains of the salt were dissolved in water, and the solution digested in a flask with carbonate of barytes—the alumina was thrown down, and a solution of nitrate of barytes formed. This solution being evaporated to dryness, left 16·245 grains of nitrate of barytes. Now, 16·245 grains of nitrate of barytes contain 6·645 grains of nitric acid. This approaches so near 6·75, that it is evident the salt is a dinitrate, and composed of

1 atom nitric acid	6·75
2 atoms alumina	4·5
10 atoms water	11·25
	22·5

I made different attempts to form a nitrate of alumina, but they were all unsuccessful.

Trisnitrate, 4. Trisnitrate of alumina. I formed this salt by keeping the dinitrate of alumina on the sand

bath till it lost its liquid form, and became a white dry crust. In this state it was nearly insoluble in water, though it was not quite destitute of taste; it did not deliquesce when exposed to the air.

20·25 grains of this salt being kept for half an hour in a strong red heat, left 6·75 grains of alumina, equivalent to 3 atoms of that earth.

20·25 grains being digested with carbonate of barytes, and the solution filtered and evaporated to dryness, left 16·4025 grains of nitrate of barytes, which contains 6·7 grains of nitric acid. This approaches so near 6·75 grains, that it is evident the constituents of the salt are

1 atom nitric acid	6·75
3 atoms alumina	6·75
6 atoms water	6·75
	20·25

5. Phosphate of alumina. This salt was obtained by mixing together solutions of alum, and phosphate of soda in the atomic proportions—no precipitate appears at first; but if the mixture be heated a white powder gradually falls, which is phosphate of alumina. It is tasteless, and insoluble in water; but it reddens vegetable blues powerfully. 9·125 grains of this powder, well washed, and dried in the open air, being heated to redness lost 3·375 grains. Hence, the constituents are Phosphate,

1 atom phosphoric acid	3·5
1 atom alumina	2·25
3 atoms water	3·375
	9·125

Arseniate. 6. Arseniate of alumina. This salt was obtained by mixing together solutions of alum and arseniate of soda in the atomic proportions. It is a white, tasteless, insoluble powder, not unlike phosphate of lime; but it strongly reddens vegetable blues.

16·75 grains of this salt being exposed to a red heat, lost 6·75 grains of its weight, and still reddened vegetable blues. Hence, the constituents of the salt are

1 atom arsenic acid	7·75
1 atom alumina	2·25
6 atoms water	6·75
	16·75

Chromate. 7. Chromate of alumina. This salt being very soluble in water, I could not form it by double decomposition; but when chromic acid and hydrate of alumina are long digested together, a fine yellow solution is obtained, which, however, I did not succeed in analyzing in a satisfactory manner. I ascertained merely that the salt is soluble in water, and that it has a yellow colour.

Acetate. 8. Acetate of alumina. This salt was formed

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by digesting a mixture of acetic acid and hydrate of alumina till the acid was saturated. No heat must be applied, because it occasions a precipitation of a portion of the alumina from the solution, which, however, again dissolves when the liquid cools. A portion of solution of acetate of alumina, thus formed, was left in a covered Wedgewood evaporating dish for six weeks during the summer of 1824. The whole liquid evaporated away, and left the acetate of alumina crystallized in long transparent four-sided prisms, which were so firmly attached to the dish, that they could not be removed without destroying their shape. This is the only simple salt of alumina which I have yet succeeded in obtaining in regular crystals.

The portion of this salt which I subjected to analysis was not in crystals, but in the state of a powder obtained by exposure to a very gentle heat. 9·625 grains of it kept for some time in a red heat, left 2·25 grains of alumina. Hence the constituents of the salt are

1 atom acetic acid	6·25
1 atom alumina	2·25
1 atom water	1·125
	9·625

The salt has a sweet and astringent taste, with something of the flavour of acetic acid, dissolves

very readily in water, and reddens vegetable blues.

Oxalate, 9. Oxalate of alumina. Oxalic acid dissolves hydrate of alumina with facility. The saturated solution is transparent and colourless; it has a sweet and astringent taste, and reddens vegetable blues. When evaporated, the oxalate of alumina remains behind in the state of a semi-transparent amber-coloured crust, very similar in appearance to gum, or albumen which has been dried in a low heat. It dissolves with facility in water, but may be exposed to the air without absorbing moisture.

10·125 grains of this salt, when kept in a red heat for some time, leave 2·25 grains of alumina. 10·125 grains of the same salt were dissolved in water, and mixed with a sufficient quantity of muriate of lime. No precipitate fell; but a slight white powder appeared when the liquid was heated. It was evaporated to dryness in a gentle heat, digested in water, and thrown on the filter. The weight of the oxalate of lime retained on the filter was 10 grains. This is very nearly equivalent to 4·5 grains of oxalic acid. From these experiments it is obvious that the constituents of the salt are

1 atom oxalic acid	4·5
1 atom alumina .	2·25
3 atoms water .	3·375
	10·125

10. Tartrate of alumina. Tartaric acid dissolves hydrate of alumina with facility. The saturated solution has an acid, astringent, and sweet taste. Being evaporated to dryness, the tartrate assumed the form of a white semitransparent viscid mass, having a slight shade of yellow, and very like gum-arabic in appearance. On exposure to the air, it became brittle; but still continued to redden vegetable blues. Tartrate,

11·625 grains of this salt, when kept for half an hour in a red heat, left 2·25 grains of alumina. I found, by another experiment, that the acid contained in 11·625 grains of this salt just saturate 4 grains of pure soda. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom alumina .	2·25
1 atom water .	1·125
	11·625

If any consequences can be drawn from the preceding list of aluminous salts, they seem all to contain water of crystallization, though the number of atoms is very various. Two of the salts contain only 1 atom of water—two contain 3—two 6—one contains 7—and one 10.

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9. PROTOSALTS OF IRON.

Iron combines with two proportions of oxygen, and both oxides are capable of combining with acids. I shall in this section consider only the salts which contain protoxide of iron for their basis.

Protosulphate,

1. Protosulphate of iron. This well known salt, when pure, is transparent, and has a light green colour; and is crystallized in oblique prisms, having a rhomb for their base. Its constituents are

1 atom sulphuric acid	5
1 atom protoxide of iron	4·5
7 atoms water .	7·875
	17·375

Protonitrate,

2. Protonitrate of iron. I obtained this salt by dissolving iron in dilute nitric acid till the acid refused to take up any more of the metal. The solution, which was at first brown and opaque, became gradually transparent by the escape of nitrous gas, and assumed a light green colour, with a shade of yellow. It was concentrated under the exhausted receiver of an air pump, over sulphuric acid. A small quantity of peroxide of iron precipitated when the greatest part of the liquid had evaporated, and pretty regular crystals of protonitrate of iron were formed.

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They were in rhomboidal prisms, were transparent, and had a light green colour; so that in appearance they bore some resemblance to protosulphate of iron. This salt reddened vegetable blues, as is the case with all the soluble salts of iron. Its taste was sweet and astringent, like that of the protosulphate of iron, but harsher.

34·8 grains of these crystals, dried on blotting paper, were exposed to the heat of a spirit lamp in a platinum vessel. The salt melted, became yellow, then brown, and fumes of nitric acid escaped. The residue was black, had the metallic lustre, and was not attracted by the magnet. It was, therefore, peroxide of iron, and weighed 8·8 grains, equivalent to 7·92 grains of protoxide of iron. The weight of the nitric acid and water contained in the 34·8 grains of salt was obviously 26·88. Now, the protoxide of iron in the salt was saturated with nitric acid. Hence, it is easy to deduce from the preceding experiment the constituents of the salt; namely,

1 atom nitric acid .	6·75
1 atom protoxide of iron	4·5
$7\frac{1}{2}$ atoms water .	8·4375
	19·6875

Probably the crystals contained only 7 atoms of

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water chemically combined in the salt; for, as the crystals were only dried on blotting paper, without much pressure, I think it likely that they might retain a little water lodged mechanically between their plates. If that supposition be correct, the true atomic weight of these crystals will be 19·125.

This salt cannot be preserved. The iron is gradually peroxydized, and the crystals deliquesce.

Protocarbonate,

3. Protocarbonate of iron. It would be difficult to form this salt artificially; but it has been found native at Eulenloh in Bareuth, and in other places, crystallized in rhombs. It has a greenish yellow colour, a certain degree of transparency, and a specific gravity of 3·333. Bucholz analyzed this mineral in the year 1803, and found its constituents as follows:

Carbonic acid .	36
Protoxide of iron .	59
Lime . . .	3
Water . . .	2
	100 *

The carbonic acid was estimated by the weight lost during the solution of the salt in muriatic acid. The water was obtained by heating the salt to redness in a receiver. The lime was cal-

* Gehlen's Jour. I. 231.

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culated from 5½ grains of carbonate obtained during the experiment. Bucholz estimated it at 2·5 grains, but the true quantity is obviously 3 grains. The protoxide of iron was the quantity requisite to make up the 100 grains analyzed. Now, if the salt were a compound of

1 atom carbonic acid	2·75	or	36
1 atom protoxide of iron	4·5	-	59
	7·25		

we obtain the very constituents of Bucholz. The lime, consequently, must have been accidentally present, and not in the state of combination. The water, amounting only to $\frac{1}{8}$th atom, must have been mechanically mixed.

4. Protophosphate of iron. This salt, in beautiful transparent crystals of a light blue colour, and having the shape of right oblique prisms, has been found in Cornwall, and likewise in Brazil and the Isle of France. A variety from Eckartsberg, in round nodules, and not crystallized, was analyzed by Klaproth, who found its constituents Protophosphate,

Phosphoric acid	32
Protoxide of iron	47·5
Water	20
	99·5 *

* Beitrage, IV. 122.

This approaches

1 atom phosphoric acid	3·5
1 atom protoxide of iron	4·5
2 atoms water . .	2·25
	10·25

But this differs a good deal from the result of Laugier's analysis of the crystals.

The phosphate of iron, which occurs in fine transparent blue crystals, was analyzed by Stromeyer, and found composed of

Phosphoric acid .	2·73
Protoxide of iron .	3·64
Water . .	2·42
	8·79 *

This is obviously

1 atom phosphoric acid	3·5
1 atom protoxide of iron	4·5
3 atoms water . .	3·375
	11·375

Diprotarseniate,

5. Diprotarseniate of iron. This salt is found native, crystallized in small cubes, which have a dark green colour, and a specific gravity of 3. It may be formed artificially by mixing together solutions of arseniate of ammonia and pro-

* Untersuchungen, I. p. 274.

tosulphate of iron. Its constituents, according to the analysis of Chenevix, are

Arsenic acid	38	or	7·75
Protoxide of iron	43	-	8·77
Water . .	19	-	3·875
	100		

The last column gives the proportions of the constituents, supposing the quantity of arsenic acid to be 7·75, or an atom. 8·77 approaches very near 9, which is 2 atoms protoxide of iron; and 3·875 is very near 3·9375, or 3½ atoms water. The true constitution of the salt is probably

1 atom arsenic acid .	7·75
2 atoms protoxide of iron	9
3 atoms water . . .	3·375
	20·125

6. Protacetate of iron. This salt was first described many years ago by Sir Humphrey Davy, who gave an account of it in his *Researches*. When iron, or sulphuret of iron is dissolved in acetic acid, the solution has a light green colour, and is transparent. I attempted to filter this liquid to get rid of the undissolved iron; but the liquid absorbed oxygen from the atmosphere with inconceivable rapidity, and Protacetate,

passed through the filter opaque and almost black. I, therefore, put a quantity of the unfiltered liquid under the receiver of an air pump along with sulphuric acid, and kept it in a good vacuum till the salt became dry. By this process a portion of the salt at the surface became dark coloured; but the portion next the bottom of the vessel was in a beautiful fibrous form, and nearly white, at least the shade of green was very slight. The salt, when thus dry, might be left exposed to the air for days without undergoing any alteration. Its taste was sweet, astringent, and acid, and it reddened vegetable blues. It dissolved readily in water, and the solution becomes immediately dark coloured.

To determine its composition I dissolved 14·125 grains of it in water, and added to the solution 18 grains of crystallized carbonate of soda. The oxide of iron was all precipitated, the residual liquid contained no iron, and did not alter the colour of vegetable blues. Now, 18 grains of crystallized carbonate of soda contain 4 grains of soda, which require for saturation 6·25 grains of acetic acid, present in 14·125 grains of the salt. The iron being collected and peroxided, weighed almost exactly 5 grains, equivalent to 4·5 grains of peroxide of iron. From these experiments the salt was obviously composed of

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1 atom acetic acid	6·25
1 atom soda	4·5
3 atoms water	3·375
	14·125

No doubt the crystals of protacetate of iron described by Davy, contain more water than my fibrous salt, but I had not an opportunity of examining them, as no crystals formed when the solution was evaporated under the air pump.

7. Protoxalate of iron. This salt is easily obtained by pouring oxalic acid into a solution of protosulphate of iron; it instantly falls in the state of a beautiful yellow powder. When heated moderately on the sand bath it gives off water and becomes brown—soon after, it catches fire and burns like tinder. Its constituents are Protoxalate,

1 atom oxalic acid	4·5
1 atom protoxide of iron	4·5
2 atoms water	2·25
	11·25

8. Prototartrate of iron. This salt was obtained by mixing rather concentrated solutions of protosulphate of iron and tartrate of potash in the atomic proportions. On setting the mixture aside for twenty-four hours, a considerable deposite of tartrate of iron was found encrusting the bottom and sides of the vessel. This salt was in transparent crystals, but so irregular, Prototartrate.

that their shape could not be ascertained; the greater number of them were nearly globular. They were hard, not altered by exposure to the air, and had an inky, though weak taste. 20 grains of these crystals, when exposed to as strong a heat as they could bear without decomposition, lost 3·8 grains. When the heat was raised to about 600°, the salt blackened, and lost about 12 grains—being exposed to a red heat, the residuum was reduced to 6·3 grains—it was sensibly magnetic. It was therefore drenched with nitric acid, and exposed to a heat raised gradually almost to redness. The weight of the residue was now increased to 6·688 grains, equivalent to 6·012 grains of protoxide of iron, and 6·012 : 4·5 : : 20 : 14·97. From this it is obvious, that 15 grains of the salt contain just 4·5 grains of protoxide of iron. Consequently, its constituents must be

1 atom tartaric acid	8·25
1 atom protoxide of iron	4·5
2 atoms water	2·25
	15

The preceding list is rather too scanty to permit us to draw any inferences with respect to the water of crystallization of the ferruginous salts.

One salt, the carbonate, is anhydrous.
Two, the protoxalate and prototartrate, contain 2 atoms water.
Three, the phosphate, diprotarseniate, and acetate, contain 3 atoms water.
Two, the sulphate and nitrate, contain 7 atoms water.

It has been already observed, that the chromate of iron does not exist.

10. PERSALTS OF IRON.

Few of these salts being capable of crystallizing, they have not hitherto been subjected to a rigid examination; most of them, as far as my experience goes, are sesquisalts, agreeing with Gay-Lussac's law, that the quantity of acid necessary to saturate an oxide increases with its oxygen; but to this rule there occur many exceptions.

Persesquisulphate.

1. Persesquisulphate of iron. When a portion of protosulphate of iron is peroxidized by means of nitric acid, and cautiously concentrated till the whole nitric acid is dissipated, we obtain a red coloured mass, which dissolves only partially in water. The solution has a red colour with a tint of yellow—the taste is astringent and very harsh. When evaporated to dryness it speedily absorbs moisture, and deliquesces into a liquid —alcohol dissolves it readily. It strongly red-

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dens vegetable blues. This salt, abstracting the water which could not be determined, is composed of

1½ atom sulphuric acid	7·5
1 atom peroxide of iron	5
	12·5

Pertetrasulphate,

2. Pertetrasulphate of iron. The insoluble portion remaining after the persesquisulphate of iron has been extracted, is a red coloured powder destitute of taste, and insoluble in water. It is anhydrous, and composed of

1 atom sulphuric acid	5
4 atoms peroxide of iron	20
	25

It is, therefore, a pertetrasulphate of iron.

Persesquinitrate,

3. Persesquinitrate of iron. This salt forms large and pretty regular crystals. It was first noticed by Vauquelin, above 20 years ago, who formed it by leaving nitric acid for a long period in contact with black oxide of iron. The crystals form spontaneously in the liquid. The crystals, when first formed, are transparent and colourless, but when kept for some time they acquire a brownish tinge; I have obtained them in flat colourless rhomboids, and in four-sided right prisms with square bases. The prisms are frequently six-sided from the truncature of two

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of the edges of the prism, or eight-sided from the truncature of all the edges. The taste is astringent and acid, and the crystals redden vegetable blues very powerfully. They deliquesce rapidly when exposed to the air; when heated, they melt in their water of crystallization, and the liquid has a deep yellowish red colour. The rapidity with which these crystals absorb water makes it difficult to analyze them with perfect accuracy.

I found that 50 grains of them, when gradually evaporated to dryness and finally exposed to a red heat, leave very nearly 10 grains of peroxide of iron.

24·125 grains of the crystals were dissolved in water, and the solution mixed with a solution of 10·125 grains of anhydrous carbonate of soda. When the iron had subsided and the carbonic acid had been allowed time to dissipate, the residual liquid was found to have the property of giving a slightly purple colour to cudbear paper; but when one drop of muriatic acid was added this property was destroyed, and the liquid reddened litmus paper. Hence, I conceive that the acid in 24·125 grains of the salt is just neutralized by the soda in 10·125 grains of anhydrous carbonate of soda. But 10·125 carbonate of soda is equivalent to 1½ atom of soda; consequently, 24·125 of the salt must contain 1½ atom of nitric acid. The water absorbed by the crys-

tals, while weighing, accounts for the small surplus of soda in the liquid after mixture: this is also the reason of the slight deficiency of oxide of iron found in the first part of the analysis. The salt is obviously composed of

1½ atom nitric acid	10·125
1 atom peroxide of iron	5
8 atoms water .	9
	24·125

Subpernitrate,

4. Subpernitrate of iron. This salt, obtained by drying the pernitrate in rather a high temperature, has been analyzed by M. Grouselle, who found its constituents as follows:

1 atom nitric acid	6·75
8 atoms peroxide of iron	40
2 atoms water .	2·25
	49*

Persesquiphosphate,

5. Persesquiphosphate of iron. This salt is easily formed by mixing solutions of persulphate of iron and phosphate of soda together in the requisite proportions. It is a white powder, tasteless and insoluble in water.

To determine the composition of this salt I proceeded in the following way:—173·75 grains (equivalent to 10 atoms) of the crystals of pro-

* Ann. de Chim. et de Phys. XIX. 138.

tosulphate of iron were dissolved in water, and the oxide peroxidized by digesting the solution with a little nitric acid. After the peroxidation was completed, I saturated the excess of nitric acid still remaining, as nearly as possible, by ammonia, and added a solution of 315 grains (equivalent to 15 atoms) of phosphate of soda. After the perphosphate of iron had subsided, I found that the residual liquid still contained iron, owing to an excess of nitric acid which it still contained; but on adding a few drops of ammonia, a little perphosphate of iron precipitated, and the liquid was now perfectly free from iron. The perphosphate of iron thus obtained, was dried on the filter in a gentle heat; when it ceased to lose weight it was weighed, and then exposed to a red heat; the loss of weight was noted, and considered as water. The anhydrous salt was now composed of peroxide of iron and phosphoric acid.

The peroxide of iron from 173·75 grains of protosulphate of iron is 50 grains; the phosphoric acid in 315 grains of phosphate of soda is 52·5 grains. Now, the anhydrous salt only exceeded 102·5 grains by about 2 grains; hence, it is evident that the anhydrous salt is a persesquiphosphate of iron. 19·25 grains of the salt, as dried on the filter, when exposed to a strong red heat, underwent a kind of semifusion, and

lost 9 grains of its weight. Hence, the constituents of this salt are

1½ atom phosphoric acid	5·25
1 atom peroxide of iron	5
8 atoms water . .	9
	19·25

Pertrisphosphate.

6. Pertrisphosphate of iron. When the preceding salt is digested in caustic potash ley it assumes a deep brownish red colour. The new salt thus formed is tasteless and insoluble in water. When heated to redness, the colour becomes darker, indeed almost black. I find, that when 21·875 grains of this salt, dried on the filter in a gentle heat, are heated to redness in a platinum crucible, the loss of weight is 3·5 grains; which is equivalent to 3 atoms water very nearly. I found that 50 grains of persesquiphosphate of iron, when digested in potash ley, left 19 grains of the red salt after exposure to redness;—knowing the quantity of peroxide of iron in the persesquiphosphate, it is easy to see that the red salt is composed of

1 atom phosphoric acid	3·5
3 atoms peroxide of iron	15
3 atoms water . . .	3·375
	21·875

It is, therefore, a pertrisphosphate of iron.

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11. SALTS OF NICKEL.

Only the protoxide of nickel, as far as is known, combines with bases. These salts have hitherto been very imperfectly investigated.

1. Sulphate of nickel. This salt has a beautiful grass green colour, and crystallizes in two forms: 1. Rhombic prisms, exactly similar to those of sulphate of zinc. 2. In square prisms. This last is the form which they assume when there is an excess of acid in the solution;—I have analyzed both without finding any difference between them. Mr. R. Phillips found a very slight excess of acid in the square prisms, which was probably only mechanically lodged between the plates of the crystals. The constituents of this salt are Sulphate,

1 atom sulphuric acid	5
1 atom protoxide of nickel	4·25
7 atoms water . .	7·875
	17·125

2. Nitrate of nickel. This salt crystallizes in four-sided oblique prisms; it has a green colour, not quite so fine as that of sulphate of nickel. I do not find it to undergo any alteration though left exposed to the air. Its composition, according to the analysis of it made in my laboratory, is as follows: Nitrate,

1 atom nitric acid .	6·75
1 atom protoxide of nickel	4·25
5 atoms water . .	5·625
	16·625

Carbonate. 3. Carbonate of nickel. This salt is easily obtained by precipitating a solution of sulphate of nickel by carbonate of soda, collecting the precipitate upon a filter, and allowing it to dry in the open air, after having been thoroughly washed. It is a light green tasteless powder, insoluble in water; but dissolving with effervescence in acids. 20 grains of it, when exposed to the heat of a spirit lamp in a platinum crucible, give out water and carbonic acid; and a black powder remains, weighing 10·58 grains, equivalent to 9·466 grains protoxide of nickel. Hence, the constituents of the salt are

Carbonic acid	6·125	or	2·75
Protoxide of nickel	9·466	-	4·25
Water . . .	4·409	-	3·385
	20·000		

The last column, giving us the ratios of the constituents, shows that the composition of the salt is

1 atom carbonic acid .	2·75
1 atom protoxide of nickel	4·25
3 atoms water . . .	3·375
	10·375

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1 atom arsenic acid .	7·75
1 atom protoxide of nickel	4·25
6 atoms water	6·75
	18·75

At the temperature of 500°, it parts with 4 atoms of water; but retains 2 atoms.

Binarseniate,

6. Binarseniate of nickel. When arsenic acid is digested upon carbonate of nickel, no apparent action is perceptible for some time; but in a few days the liquid acquires a fine green colour, and the portion of carbonate of nickel which does not dissolve assumes the peculiar shade of green which characterizes the arseniate of nickel while moist. When all action was at an end, the liquid was filtered, and gently evaporated to dryness, on the sand bath. No crystals appeared; but a yellowish green matter was deposited, rather bulky, and having a good deal of clamminess. To free it from adhering moisture, it was placed between the folds of blotting paper, and exposed for 24 hours to considerable pressure. In this state it was insoluble in water, had a slightly acid taste, and reddened vegetable blues powerfully. It was, therefore, a binarseniate of nickel. 50 grains of it, when exposed to a red heat, became yellow, and lost 18·5 grains of its weight; but it still reddened vegetable blues as powerfully as ever. From this experiment I consider the salt as a compound of

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2 atoms arsenic acid	15·5
1 atom oxide of nickel	4·25
10 atoms water .	11·25
	31

7. Chromate of nickel. This salt was obtained by mixing together solutions of chromate of potash and sulphate of nickel. No precipitate appears at first, but a reddish brown powder gradually falls; and the precipitate is increased by evaporating the liquid. This deposite, when washed and dried, is rather a beautiful reddish brown powder, destitute of taste, and not affecting vegetable blues. 15·2 grains of it, when heated to redness, assumed an olive green colour, and lost 4·45 grains of weight. Hence it was a compound of Chromate,

1 atom chromic acid	6·5
1 atom oxide of nickel	4·25
4 atoms water .	4·5
	15·25

8. Acetate of nickel. This salt was obtained by dissolving carbonate of nickel in very strong acetic acid. The carbonate dissolved rapidly with a strong effervescence. The saturated solution is dark green. When set aside, it gradually deposites acetate of nickel in light green crystals. The form of these crystals is a rhom- Acetate,

boid; but the salt has a great tendency to concrete at the bottom of the vessel in the form of saline crusts, without any regular form. This salt is very soluble in water, and slightly reddens vegetable blues, even after having been twice crystallized. Its taste is at first sweetish, then it leaves an impression similar to that of sulphate of zinc, but much weaker. When exposed in a platinum crucible to the heat of a spirit lamp, it did not melt; but gave out water, having a slight smell of acetic acid, and a weak acidulous taste, and gradually assumed a yellowish green colour. It then took fire, and burned like tinder, leaving an oxide, which was digested in nitric acid to convert it into peroxide of nickel. 50 grains of the crystals, when treated in this way, left 14·71 grains of peroxide of nickel, equivalent to 13·1615 grains of protoxide. From this experiment it follows, that acetate of nickel is composed of

Acetic	19·3551	or	6·25
Protoxide of nickel	13·1615	-	4·25
Water	17·4834	-	5·645
	50·0000		

5·645 differs so little from 5·625, or 5 atoms of water, that we can have no hesitation about considering the salt as composed of

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1 atom acetic acid .	6·25
1 atom protoxide of nickel	4·25
5 atoms water .	5·625
	16·125

9. Oxalate of nickel. This salt was obtained by mixing together solutions of sulphate of nickel and oxalate of ammonia in the atomic proportions. For some minutes the mixture retained its transparency, but by degrees it became opaque, and oxalate of nickel was slowly deposited. Very nearly the whole oxalic acid and oxide of nickel were deposited; only traces of them could be detected in the supernatant liquid. The oxalate of nickel, when well washed and dried in the air, was a light green powder destitute of taste, and insoluble in water. Oxalate.

20 grains of this salt when heated on the sand bath lost 1·66 grains. It was now exposed to a red heat till thoroughly calcined. There remained a dark brown powder which did not effervesce nor dissolve in cold nitric acid, though a solution was slowly effected by the assistance of heat: hence, it was peroxide of nickel. It weighed 7 grains, equivalent to 6·263 grains of protoxide of nickel. The constituents of the salt from this experiment, were

Oxalic acid	6·631	or	4·5
Protoxide of nickel	6·263	-	4·25
Water	7·106	-	4·822
	20·000		

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Hence, there can be no doubt that the salt is a compound of

1 atom oxalic acid	4·5
1 atom protoxide of nickel	4·25
4 atoms water	4·5
	13·25

The 0·322 of surplus water found by experiment, was no doubt lodged mechanically in the powder. It is scarcely possible to avoid such slight excesses of water, when we examine a salt which forms only a powder, because there is no criterion by which we can know when all the hygrometrical water is driven off; and in many cases it would be hazardous to attempt to drive it off by heat. On the sand bath the salt loses very nearly, but not quite, an atom of water: for 13·25 grains would have lost 1·09975 grains. Probably, had the heat been continued long enough, the loss would have amounted to exactly an atom, leaving 3 atoms of water still united to the salt.

Tartrate. 10. Tartrate of nickel. This salt was formed by dissolving carbonate of nickel in tartaric acid; a green solution was obtained, which, when evaporated to dryness, left a light olive green powder, which was tasteless, insoluble in water, and producing no alteration on vegetable blues. It was anhydrous, for 12·88 grains, when exposed to the strongest heat which it could

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bear without decomposition, lost only 0·38 grain, equivalent to one-third of an atom, evidently hygrometrical. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom protoxide of nickel	4·25
	12·5

The salts of nickel, in general, contain a good deal of water of crystallization, though like the other genera, there is a considerable difference in this respect between the species. The tartrate alone is anhydrous—the carbonate and phosphate contain 3 atoms water—the oxalate and chromate 4—the nitrate and acetate 5—the arseniate contains 6—the sulphate 7, and the binarseniate 10.

12. SALTS OF COBALT.

1. Sulphate of cobalt. This salt has a deep red colour, and crystallizes in rhombic prisms, similar to the form of sulphate of iron. Its constituents are Sulphate,

1 atom sulphuric acid	5
1 atom protoxide of cobalt	4·25
7 atoms water	7·875
	17·125

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Bisulphate, 2. Bisulphate of cobalt. When sulphate of cobalt is crystallized in an excess of acid, long four-sided prisms are obtained, which speedily effloresce on the surface when exposed to the air, but do not fall to powder. These crystals contain twice as much acid as the neutral salt, and are composed of

2 atoms sulphuric acid	10
1 atom protoxide of cobalt	4·2
3 atoms water	3·375
	17·625

Nitrate, 3. Nitrate of cobalt. This salt is easily obtained by dissolving cobalt or its oxide in nitric acid. The solution has a deep red colour, and when sufficiently concentrated, deposites crystals of nitrate of cobalt, which have a red colour with a shade of brown. They seem to be rhomboids, but are always so interwoven and irregular, that it is difficult to recognise the true form. They deliquesce rather rapidly when exposed to the air. Their taste is acrid and bitter, and they redden vegetable blues.

17·75 grains of the crystals of this salt were heated in a platinum crucible. In a moderate heat they melted in their water of crystallization, and continued for a considerable time to give out nothing but pure water. At last when the greatest part of the water was dissipated, and

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the heat rather increased, fumes of nitric acid came over in abundance, and the matter in the crucible concreted into a black mass, which, after exposure to a red heat, weighed 4·8 grains: it was peroxide, and equivalent very nearly to 4·25 grains of protoxide of cobalt. 17·75 grains of the crystals were dissolved in water, and digested with carbonate of barytes till the liquid became colourless. The supernatant liquid being then drawn off and evaporated to dryness, left 15·5 grains of nitrate of barytes, equivalent to 6·34 grains of nitric acid. This is somewhat less than 6·75, the atomic weight of nitric acid. The cause of this diminution of weight is the filter, through which the solution of nitrate of barytes was passed. It contained some sulphate of lime which decomposed a portion of nitrate of barytes, substituting nitrate of lime in its place. From the preceding analysis it is evident, that the constituents of this salt are

1 atom nitric acid .	6·75
1 atom protoxide of cobalt	4·25
6 atoms water .	6·75
	17·75

4. Carbonate of cobalt. This salt was obtained by precipitating the nitrate of cobalt by carbonate of soda, collecting the precipitate on a filter, and washing it thoroughly with water. When dry, it is a light powder having a pink Carbonate,

colour of no great depth of shade, and destitute of beauty. It is tasteless, insoluble in water, and not altered by exposure to the air. It does not alter vegetable blues, but dissolves in acids with a strong effervescence.

8·125 grains of this salt were exposed to a red heat in a platinum crucible; there remained a black powder weighing 4·75 grains. It was peroxide of cobalt, and equivalent to 4·25 grains of protoxide: hence, the constituents of the salt are

1 atom carbonic acid	2·75
1 atom protoxide of cobalt	4·25
1 atom water	1·125
	8·125

Phosphate, 5. Phosphate of cobalt. This salt was prepared by dissolving carbonate of cobalt in phosphoric acid and mixing the solution with alcohol. A copious precipitate falls, which was collected on a filter, and edulcorated first with alcohol and then with water. It was gelatinous, and had a fine crimson colour. When dried, it concreted into a hard dark red matter, which reddened vegetable blues. 10 grains of it, when heated to redness, lost very nearly 2·25 grains; hence, I consider the salt as composed of

1 atom phosphoric acid	3·5
1 atom protoxide of cobalt	4·25
2 atoms water	2·25
	10

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6. Arseniate of cobalt. This salt is easily obtained by mixing together solutions of nitrate of cobalt and arseniate of soda, and evaporating the solution. The arseniate falls in the state of a crimson coloured jelly, which, when washed and dried, assumes the form of scales. It is light, and has a fine crimson colour; is tasteless, and does not alter the colour of vegetable blues. When 16·5 grains of this salt were exposed to a red heat, the loss of weight was 5 grains; hence, I am disposed to consider it as a compound of Arseniate,

1 atom arsenic acid	7·75
1 atom protoxide of cobalt	4·25
4 atoms water	4·5
	16·5

The loss of weight would indicate very nearly 4½ atoms water; but the half atom was probably only mechanically lodged between the particles of the salt.

7. Binantimoniate of cobalt.- This is a red coloured salt not quite insoluble in water, which was analyzed by Berzelius; and from his experiments it appears that it is a compound of Binantimoniate,

2 atoms antimonic acid	15
1 atom protoxide of cobalt	4·25
8 atoms water	9
	28·25

The water found by Berzelius amounted to one

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third the weight of the salt; which exceeds 8 atoms a little. Probably the excess, which amounts to about half an atom, was only mechanically mixed with the salt and not chemically combined.

Chromate, 8. Chromate of cobalt. This salt was obtained by mixing solutions of chromate of potash and nitrate of cobalt together. The chromate gradually fell down, of a reddish brown colour; it had no taste, and produced no change on vegetable blue colours. 12·85 grains of it when exposed to a red heat, assumed an olive green colour, and lost 2·1 grains of its weight. Hence, the constituents of the salt are

1 atom chromic acid	6·5
1 atom oxide of cobalt	4·25
2 atoms water	2·25
	13·0

Oxalate, 9. Oxalate of cobalt. This salt is easily obtained by mixing together the solutions of nitrate of cobalt and oxalate of ammonia. The precipitate is to be collected on a filter, well washed and dried in the open air. It is a light red powder, destitute of taste, insoluble in water, and incapable of altering the colour of vegetable blues. 11 grains of this salt, when heated upon the sand bath, lose 2·25 grains of water; and leave, when calcined, 4·25 grains of protoxide of cobalt. Hence, the constituents are

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1 atom oxalic acid	4·5
1 atom protoxide of cobalt	4·25
2 atoms water	2·25
	11

10. Tartrate of cobalt. This salt was obtained by dissolving oxide of cobalt (from an ammoniacal solution) in tartaric acid. By digesting the acid over the oxide for twenty-four hours, a fine crimson solution was obtained, which, when concentrated by evaporation, let fall a red precipitate having a most beautiful crimson colour. This precipitate was put on a filter and washed with water two or three times to remove any excess of acid that might adhere to it; it was slightly soluble in water, for by this process its quantity was sensibly diminished, while the water with which it was washed came off red. The matter was now dried on the filter in a gentle heat; it had a fine crimson colour, little or no taste, but it reddened vegetable blues. 7·8 grains of this salt, being exposed to the highest temperature they could bear without decomposition, lost 1·25 grains of their weight: leaving 6·55 grains of tartrate still retaining its fine colour. Now, Tartrate.

6·55 : 12·5 : : 1·25 : 2·371 = water combined with an integrant particle of anhydrous salt.

This shows us that the constituents of the salt are

1 atom tartaric acid	8·25
1 atom protoxide of cobalt	4·25
2 atoms water . .	2·25
	14·75

All the salts of cobalt, if we can judge from the preceding list, contain water of crystallization. But the quantity is in general less than in the salts of nickel. The carbonate contains only 1 atom—the phosphate, oxalate, tartrate, and chromate contain 2 atoms—the bisulphate 3—the arseniate 4—the nitrate 6—the sulphate 7, and the biantimoniate 8 atoms.

13. SALTS OF MANGANESE.

The salts of manganese are most of them agreeable to the eye, particularly the sulphate and the acetate. They are transparent, and have a slight tinge of flesh red, or rather violet red, which adds greatly to their beauty.

Sulphate, 1. Sulphate of manganese. This salt crystallizes in very flat rhombic prisms, the greater angle of which is about 148°; its taste is similar to that of glauber salt, and it may be substituted for that salt as a purgative. Its constituents are

1 atom sulphuric acid	5
1 atom protoxide of manganese	4·5
5 atoms water . .	5·625
	15·125

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When the solution is concentrated rather too much for crystallization, a white crust is deposited upon the bottom of the vessel: this crust is rather difficultly soluble in water, and is a compound of 1 atom of the anhydrous salt with 3 atoms of water.

2. Nitrate of manganese. This salt is not easily obtained in regular crystals; its colour is similar to that of the carbonate; when exposed to the air it speedily deliquesces. Its constituents are Nitrate,

1 atom nitric acid . .	6·75
1 atom protoxide of manganese	4·50
7 atoms water . . .	7·875
	19·125

3. Carbonate of manganese. This is a white tasteless powder, insoluble in water; when kept for some time it is partly converted into black oxide of manganese. Its constituents, according to the analysis of Dr. Forchhammer, are as follows: Carbonate,

1 atom carbonic acid . .	2·75
1 atom protoxide of manganese	4·5
1 atom water . . .	1·125
	8·375

I find, that when it is merely dried in the open air, without any artificial heat, it contains 2 atoms

of water. 100 grains of this carbonate were dissolved in nitric acid, the solution was evaporated to dryness, and heated till the acid was destroyed, and black shining deutoxide of manganese remained behind. It weighed 50·55 grains, equivalent to 45·495 grains of protoxide, which would require for saturation 27·801 grains of carbonic acid; consequently, the constituents of the carbonate must have been

Carbonic acid .	27·8	or	2·75
Protoxide of manganese	45·5	-	4·50
Water . . .	26·7	-	2·25 + 0·375
	100·0		9·5

The 0·375 of water above the 2 atoms, was probably mere hygrometric water, as no attempt was made to free it from all water mechanically lodged among its particles before dissolving it in nitric acid.

Phosphate, 4. Phosphate of manganese. This salt may be obtained by mixing together solutions of sulphate of manganese and phosphate of soda. The phosphate of manganese precipitates in the state of a white powder, which may be collected on a filter, washed and dried in the open air; it is tasteless, insoluble in water, and produces no alteration on vegetable blues. 10·7 grains of this salt, when heated to redness, give out 2·7 grains of water, and leave 8 grains of anhydrous phos-

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phate of manganese. If we admit the excess of water (rather less than half an atom) to be hygrometric, the constituents of the salt will be

1 atom phosphoric acid . .	3·5
1 atom protoxide of manganese	4·5
2 atoms water . . .	2·25
	10·25

5. Arseniate of manganese. This salt may be obtained by mixing solutions of sulphate of manganese and arseniate of soda; it is a white tasteless powder, insoluble in water, and producing no alteration on vegetable blues. 23·5 grains of this salt being exposed to a red heat lost 11·25 grains; hence, the constituents are Arseniate,

1 atom arsenic acid . .	7·75
1 atom protoxide of manganese	4·5
10 atoms water . . .	11·25
	23·5

The binarseniate of manganese is soluble and easily formed. I have made no experiments to determine its composition.

6. Chromate of manganese. Protoxide of manganese decomposes chromic acid, so that the salt does not exist. Chromate,

7. Acetate of manganese. This is a beautiful salt which crystallizes in flat rhombic prisms, Acetate,

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which are not altered by exposure to the air. They are composed of

1 atom acetic acid . .	6·25
1 atom protoxide of manganese	4·5
4 atoms water . . .	4·5
	15·25

Protoxalate,

8. Protoxalate of manganese. This salt may be formed by mixing rather concentrated solutions of oxalate of potash and sulphate of manganese. No immediate precipitation ensues; but after some time the mixture becomes muddy and the salt subsides. It is a very soft tasteless powder, having a white colour, with a very slight shade of pink; it is insoluble in water, and produces no change on vegetable blues; when moderately heated it gives out abundance of water. Being analyzed by driving off the water on the sand bath, and then calcining it in a strong red heat, its constituents were found to be

1 atom oxalic acid . .	4·5
1 atom protoxide of manganese	4·5
3 atoms water . . .	3·375
	12·375

Tartrate,

9. Tartrate of manganese. This is a beautiful transparent salt, having rather a deep brownish red colour; the crystals are four-sided prisms, exceedingly little soluble in water. This salt has

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hitherto been mistaken for a triple salt, but it contains no potash. Its constituents are

1 atom tartaric acid . .	8·25
1 atom protoxide of manganese	4·5
2 atoms water . . .	2·25
	15

All the salts of manganese included in the preceding list contain water of crystallization. The smallest quantity of water is 2 atoms and the greatest 10 atoms. The carbonate, phosphate, and tartrate contain 2 atoms—the oxalate contains 3—the acetate 4—the sulphate 5—the nitrate 7—and the arseniate 10 atoms.

14. SALTS OF ZINC.

1. Sulphate of zinc. This salt crystallizes in right rhombic prisms,—frequently the prisms are terminated by four-sided pyramids. The figure of the crystals is modified a good deal by the excess of acid allowed to remain in the liquid from which the crystals are to be separated. I have never been able to obtain this salt, though ever so frequently crystallized, in a state in which it did not redden vegetable blues. Sulphate.

The analyses of two varieties have been detailed in the first section of the first chapter of this work; I shall merely give the results in this place.

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(1.) Sulphate of zinc deposited from a cold solution :

1 atom sulphuric acid	5
1 atom oxide of zinc .	5·25
7 atoms water . .	7·875
	18·125

(2.) Sulphate deposited from a hot solution :

1 atom sulphuric acid	5
1 atom oxide of zinc .	5·25
3 atoms water . .	3·375
	13·625

Nitrate, 2. Nitrate of zinc. This salt has an exceedingly disagreeable taste, and may be obtained, with difficulty, in flat four-sided prisms, which deliquesce so rapidly, that it is not an easy task to obtain the salt in a state fit for analysis. Its constituents are

1 atom nitric acid .	6·75
1 atom oxide of zinc .	5·25
6 atoms water . .	6·75
	18·75

Carbonate, 3. Carbonate of zinc. Two species of this salt are found native, and constitute a part of the bodies confounded by mineralogists under the name of *calamine*.

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(1.) Anhydrous carbonate. It occurs crystallized in very small obtuse rhomboids. It has a yellowish white colour, and a specific gravity of 4·334; it dissolves with effervescence in sulphuric acid, and is composed of

1 atom carbonic acid	2·75
1 atom oxide of zinc	5·25
	8

Carbonate of zinc, obtained by precipitating sulphate of zinc by carbonate of soda, washing the precipitate, and drying it at 212°, is likewise anhydrous.

(2.) Hydrous carbonate of zinc. It has not yet been met with in crystals; but it has a white colour, or yellowish white colour, and is most commonly stalactical. Its specific gravity is 3·584; it dissolves with effervescence in sulphuric acid, and does not gelatinize with acids. Its constituents are

1 atom carbonic acid .	2·75
1 atom oxide of zinc .	5·25
1 atom water . .	1·125
	9·125

4. Phosphate of zinc. This salt may be obtained by mixing together solutions of sulphate of zinc and phosphate of soda in the atomic proportions. The phosphate of zinc immediately appears in white flocks, which are soon deposited in a pulverulent form. When dried in the Phosphate,

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open air it is a white tasteless powder, which does not alter vegetable blues; it is insoluble in water. 11 grains of this salt, when exposed to a red heat, give out 2·25 grains of water; hence, the constituents are

1 atom phosphoric acid	3·5
1 atom oxide of zinc .	5·25
2 atoms water . .	2·25
	11·0

Biphosphate,

5. Biphosphate of zinc. I formed this salt by dissolving phosphate of zinc in phosphoric acid, and evaporating the solution. Small white coloured scales, with a silky lustre, were deposited, which constituted the salt in question. It has scarcely any taste, reddens vegetable blues, and is slightly soluble in water. When 16·75 grains of this salt were exposed to a heat gradually raised to redness, they lose 4·5 grains of weight; hence, the constituents must be

2 atoms phosphoric acid	7
1 atom oxide of zinc .	5·25
4 atoms water . .	4·5
	16·75

Arseniate,

6. Arseniate of zinc. This salt was formed by mixing solutions of sulphate of zinc and arseniate of soda in the atomic proportions. The arseniate of zinc was immediately deposited in a

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gelatinous state, which gradually assumed the form of a light milk white deposite; it continued gelatinous and transparent (exactly like silica) even after it had been collected on the filter, and washed for some hours. When dried in the open air it became an opaque white matter, like enamel; it was tasteless, insoluble in water, and did not affect vegetable blues. 22 grains of this salt being exposed to a red heat, lost 9 grains of its weight; hence its constituents are

1 atom arsenic acid .	7·75
1 atom oxide of zinc .	5·25
8 atoms water . .	9·00
	22

7. Chromate of zinc. This salt was obtained by mixing solutions of sulphate of zinc and chromate of potash in the atomic proportions. The chromate of zinc precipitated in the state of a fine yellow powder; the supernatant liquid being still yellow, was concentrated. It yielded two distinct sets of crystals intimately mixed with each other; namely, bichromate of potash, and sulphate of zinc tinged yellow by chromate of potash. Chromate of zinc is nearly tasteless, but it is soluble in water; for the liquid with which it was washed was yellow, and yielded, when evaporated, chromate of zinc. Chromate of zinc dried in the open air loses no weight Chromate,

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when exposed to a red heat. Hence, the salt is anhydrous, and its constituents are

1 atom chromic acid	.	6·5
1 atom oxide of zinc	.	5·25
		11·75

Acetate,

8. Acetate of zinc. This salt crystallizes in large very oblique rhombs. It has a silky lustre, and, indeed, bears a very close resemblance to talc in its appearance; when kept for some time it is apt to lose a little of its acid. Its constituents, supposing it examined when in a state of purity, are

1 atom acetic acid	.	6·25
1 atom oxide of zinc	.	5·25
7 atoms water	.	7·875
		19·375

Oxalate,

9. Oxalate of zinc. This salt may be obtained by mixing together solutions of sulphate of zinc and oxalate of ammonia in the atomic proportions. For a few seconds the mixture continues transparent, but it gradually becomes muddy, and deposites oxalate of zinc in abundance: the decomposition is complete, for no traces of oxalic acid or oxide of zinc can be found in the supernatant liquid. 181·25 grains of sulphate of zinc and 88·75 grains of oxalate of ammonia, gave 118 grains of oxalate of

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zinc;—had the quantity been 120 grains, it is obvious that its constituents would have been

1 atom oxalic acid .	4·5
1 atom oxide of zinc .	5·25
2 atoms water . .	2·25
	12·0

The loss of the two grains was owing to the filter on which the oxalate of zinc was collected.

10. Tartrate of zinc. This is a soft white tasteless powder like chalk. It is anhydrous; for 13·5 grains of it being calcined in a platinum crucible left 5·25 grains of oxide of zinc. Hence, its constituents are Tartrate,

1 atom tartaric acid .	8·25
1 atom oxide of zinc .	5·25
	13·5

The salts of zinc, as far as we can judge from the preceding list, vary a good deal in their water of crystallization, though the quantity is rather small,—eight atoms of water being the greatest number found in any salt hitherto analyzed. Carbonate, chromate, and tartrate, are anhydrous—hydrous carbonate contains 1 atom water—phosphate and oxalate 2 atoms—sulphate, from a hot solution, 3—biphosphate 4—nitrate 6—sulphate and acetate 7—and arseniate

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8 atoms. No salt of zinc examined contains 5 atoms of water.

15. SALTS OF CADMIUM.

I have mentioned in a former chapter of this work, that by the kindness of Mr. Harepath of Bristol, I was favoured with a quantity of the sublimation that attaches itself to the roof of the apartment in which zinc is smelted. This sublimate had a pretty deep brown colour, and contained a good deal of vegetable matter. After a few preliminary trials, I found that it contained about ten per cent. of oxide of cadmium; by far the greatest portion of the remainder was oxide of zinc. I therefore dissolved it in sulphuric acid, and precipitated the cadmium by means of a plate of zinc. I obtained by this simple process, about 500 grains of metallic cadmium, which enabled me, not merely to verify the experiments of Stromeyer, but to make a set of experiments on the salts of that metal: for with the exception of the sulphate and nitrate, Stromeyer has not determined the water of crystallization which they contain. I shall here state the results of these investigations.

Sulphate, 1. Sulphate of cadmium. I have given a description of this salt in a former part of this work. Its constituents, when in crystals, are

1 atom sulphuric acid	5
1 atom oxide of cadmium	8
4 atoms water	4·5
	17·5

It is so apt to lose a portion of its water of crystallization, that its analysis is not easily made; when it precipitates in a white crust it contains only 2 atoms of water.

2. Nitrate of cadmium. This salt, crystallized in vacuo over sulphuric acid, formed thin transparent plates; they deliquesce when exposed to the air, as Stromeyer had observed. 19·25 grains of these crystals were dissolved in water, and precipitated at a boiling temperature by carbonate of soda. The carbonate of cadmium, after ignition, weighed in one experiment 7·955 grains, and in another 7·912 grains. Hence, it is obvious, that the constituents are Nitrate,

1 atom nitric acid	6·75
1 atom oxide of cadmium	8·0
4 atoms water	4·5
	19·25

The constituents, as stated by Stromeyer, are as follows:

Nitric acid	6·884
Oxide of cadmium	8·114
Water	4·208
	19·206

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While the analysis in my laboratory gave

Nitric acid	6·750
Oxide of cadmium	7·933
Water	4·608
	19·291

The mean of both gives the atomic weight of cadmium 8·023, and of the salt 19·2485; both of which are exceedingly near the truth.

Carbonate, 3. Carbonate of cadmium. This is a white tasteless powder, having a certain resemblance in colour to white lead. It is destitute of combined water, but when dried in the open air retains the fifth part of an atom of water, no doubt hygrometrically united to the salt. Its constituents (abstracting this water) are

1 atom carbonic acid	2·75
1 atom oxide of cadmium	8
	10·75

Phosphate, 4. Phosphate of cadmium. This salt was formed by mixing together solutions of nitrate of cadmium and phosphate of soda. The precipitate is at first very bulky, but afterwards dimishes much in volume; it is tasteless and insoluble in water. 21·12 grains of this salt dried in the air, when exposed for 20 minutes to a low red heat, were reduced to 18·905 grains. In a very strong red heat it was reduced to a semi-

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opaque glass, and weighed 18·68 grains. From this experiment I consider it as a compound of

1 atom phosphoric acid	3·5
1 atom oxide of cadmium	8
1 atom water	1·125
	12·625

There was about one-third of an atom of surplus water, which was of course hygrometrical.

5. Arseniate of cadmium. When arseniate of soda is added to a solution of nitrate of cadmium, a white precipitate falls, at first very bulky, but in a few hours it contracts much in size. This salt is a white tasteless powder, which is insoluble in water. 21·84 grains of this salt dried in the open air, when exposed to a pretty strong red heat, were reduced to 20·01 grains; hence, 15·75 grains of the anhydrous salt must unite to 1·44 grains of water to be brought into the state of the precipitated salt dried in the open air. The constituents of this salt then are Arseniate,

1 atom arsenic acid	7·75
1 atom oxide of cadmium	8
1 atom water	1·125
	16·875

The 0·315 of superfluous water was of course mechanically lodged among the particles of the salt.

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Chromate, 6. Chromate of cadmium. This salt was obtained by mixing together solutions of sulphate of cadmium and chromate of potash. The chromate falls in the state of a most beautiful yellow coloured powder; it has little or no taste, yet it is not absolutely insoluble in water: for when washed on the filter, the liquid always passes through of a yellow colour. And in one of my experiments, I dissolved almost the whole of a quantity of chromate of cadmium by persisting in trying to wash it till the liquid should pass through colourless. 20·525 grains of this salt, when exposed to a red heat, assumed a darker yellow colour, and lost 6 grains of its weight: hence, its constituents are

1 atom chromic acid	6·5
1 atom oxide of cadmium	8
5 atoms water	5·625
	20·125

The small surplus water was doubtless hygrometrical.

Acetate, 7. Acetate of cadmium. When a very concentrated solution of this salt is exposed for about ten days to the air, it is gradually converted into a crystalline mass, while a thick liquid remains floating above it. These crystals are very soluble in water, and undergo little change from exposure to the air. 22·13 grains of these crystals, previously dried upon blotting

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paper, were decomposed by sulphuric acid. The anhydrous sulphate of cadmium weighed 17·4 grains, equivalent to 10·7007 grains of oxide of cadmium. Hence, the constituents of the salt are

1 atom acetic acid	6·25
1 atom oxide of cadmium	8·00
2 atoms water	2·25
	16·5

8. Oxalate of cadmium. This salt is precipitated when oxalate of potash is dropped into nitrate of cadmium; it is a white, tasteless powder, insoluble in water. When 17·06 grains of this salt, previously dried in the open air, were cautiously heated on the sand bath in a platinum crucible, the loss of weight was 3·62 grains: hence, the constituents of this salt are Oxalate,

1 atom oxalic acid	4·5
1 atom oxide of cadmium	8·0
3 atoms water	3·375
	15·875

9. Tartrate of cadmium. If tartrate of potash be added in slight excess to a solution of nitrate of cadmium, there instantly falls a pretty bulky precipitate. The liquid separated from this precipitate by filtration, deposites at the end of twenty-four hours a small quantity of transparent granular crystals; the supernatant liquid still gives a slight precipitate with carbonate of Tartrate,

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soda. Hence, tartrate of cadmium is slightly soluble in water; probably nearly as soluble as tartrate of manganese. These crystals are tasteless; 10·225 grains of them heated on the sand bath for about two hours, lost their crystalline form and became white and opaque, and had lost 1·17 grain of their weight. Hence, the constituents of this salt are

1 atom tartaric acid	8·25
1 atom oxide of cadmium	8
2 atoms water	2·25
	18·5

Citrate,

10. Citrate of cadmium. Citrate of ammonia produces a remarkably bulky gelatinous precipitate in nitrate of cadmium. When 17·34 grains of this salt, previously dried in the open air upon blotting paper, were exposed to the heat of the sand bath, they lost 2·17 grains of their weight: hence, the constituents of this salt are

1 atom citric acid	7·25
1 atom oxide of cadmium	8
2 atoms water	2·25
	17·5

We see from the preceding details that the greatest quantity of water in any of the salts of cadmium is 4 atoms. One salt of cadmium, the

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carbonate, is anhydrous—two, the phosphate and arseniate, contain 1 atom of water—four, acetate, tartrate, citrate and muriate, contain 2 atoms—one, oxalate, contains 3—and two, sulphate and nitrate, contain 4 atoms.

16. SALTS OF LEAD.

1. Sulphate of lead. This salt occurs native in regular crystals, though from its insolubility it cannot be crystallized artificially. The primary form of the crystals is a right rhombic prism. It is anhydrous, though it usually contains a trace of water mechanically lodged between the plates of the crystals. Its constituents are Sulphate,

1 atom sulphuric acid	5
1 atom protoxide of lead	14
	19

2. Nitrate of lead. This salt is easily soluble in water, and may be obtained without difficulty in large white opaque crystals having a vitreous lustre, and the shape of regular octahedrons with a square basis; it is likewise anhydrous. Its constituents are Nitrate,

1 atom nitric acid .	6·75
1 atom protoxide of lead	14
	20·75

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Dinitrite, 3. Dinitrite of lead. When nitric acid is digested for a long time on an excess of litharge, a yellow coloured solution is obtained, from which precipitate beautiful yellow coloured crystals in small shining scales. The constituents of these crystals are as follows:

1 atom nitrous acid .	5·75
2 atoms protoxide of lead	28
2 atoms water . .	2·25
	36

Dinitrate, 4. Dinitrate of lead. This salt was obtained by Berzelius by precipitating nitrate of lead by too small a quantity of ammonia to throw down the whole lead. Chevreul obtained it by boiling together equal weights of nitrate of lead and protoxide, filtrating the liquid while hot, and allowing it to crystallize in close vessels. The crystals were pearl coloured scales. This salt is soluble in water, and has the sweet and astringent taste of nitrate. Its constituents are

1 atom nitric acid .	6·75
2 atoms protoxide of lead	28
	34·75

Hyponitrite, 5. Hyponitrite of lead. Berzelius obtained this salt by dissolving a given quantity of dinitrite of lead in water, adding as much sulphuric acid as would deprive it of half its lead, filter-

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ing the solution, and allowing it to crystallize spontaneously—octahedral crystals of a deep yellow colour were deposited. He analyzed these crystals, and found the constituents

Acid . .	23·925
Protoxide of lead	70·375
Water . .	5·700
	100·000

If we consider them as composed of

1 atom hyponitrous acid	4·75
1 atom protoxide of lead	14·00
1 atom water . .	1·125
	19·875

the constituents in 100 parts of the salt will be

Acid .	23·90
Oxide .	70·44
Water .	5·66
	100

Now, these numbers almost coincide with those of Berzelius, and induced me to consider the salt as a hyponitrite rather than a nitrite, which is the view taken both by Berzelius and Chevreul.

6. Carbonate of lead. This salt occurs native, and is known by the name of white lead. Its primary form is a right rhombic prism. It is anhydrous, and is composed of Carbonate,

1 atom carbonic acid	2·75
1 atom protoxide of lead	14
	16·75

Phosphate, 7. Phosphate of lead. This salt exists native, and is often crystallized in six-sided prisms. It is anhydrous; but never quite pure, containing a little muriatic acid and some oxide of iron. It is very difficult to form a neutral phosphate of lead artificially, for the acid and oxide are capable of combining in two proportions; namely, 1 atom acid and 1 atom oxide, and 1 atom acid and 2 atoms oxide; and in general variable proportions of the diphosphate mix themselves with the neutral phosphate, and render the result uncertain and inconstant. The constituents of the neutral phosphate are

1 atom phosphoric acid	3·5
1 atom protoxide of lead	14
	17·5

The constituents of the diphosphate are

1 atom phosphoric acid	3·5
2 atoms protoxide of lead	28
	31·5

Arseniate, 8. Arseniate of lead. This salt has been found native in different places. Fine crystals of it in large six-sided prisms of a yellowish co-

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lour, and translucent, occur in Huel Unity in Cornwall. If any confidence can be put in the analysis of these crystals by the late Mr. Gregor, they are composed of

1 atom arsenic acid	7·75
1½ atom protoxide of lead	21
	28·75

But the native arseniate of lead from Johann-Georgenstadt, analyzed by Chenevix and Thenard, was a compound of

1 atom arsenic acid	7·75
1 atom protoxide of lead	14
	21·75

It remains, therefore, to determine whether Mr. Gregor's results be accurate; if they be, there are obviously two native species of arseniates of lead—namely, the neutral and the sesquiarseniate.

9. Chromate of lead. This salt also occurs native, crystallized in transparent prisms having a fine orange colour. The salt is anhydrous, and composed of Chromate,

1 atom chromic acid	6·5
1 atom protoxide of lead	14
	20·5

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It is anhydrous also when obtained by precipitation. It is not unlikely that there occurs also a bichromate of a red colour, composed of

2 atoms chromic acid	13
1 atom protoxide of lead	14
	27

Molybdate. 10. Molybdate of lead. This salt occurs native in Corinthia. It is usually crystallized in small rhomboidal plates; it has a pale yellow colour, and a certain degree of transparency; it is tasteless and insoluble in water, and perfectly anhydrous. Its constituents are

1 atom molybdic acid	9
1 atom protoxide of lead	14
	23

Bitungstate. 11. Bitungstate of lead. This salt likewise occurs native; for it has been found at Zinnwalde in Bohemia in very acute four-sided pyramids, having a brown colour, and perfectly tasteless, and insoluble in water. I am not aware that any analysis of the native tungstate of lead has been made; but the artificial tungstate, formed by mixing solutions of bitungstate of ammonia and nitrate of lead, was examined by Berzelius. From his experiments it appears to be a bitungstate; consequently, its constituents must be

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2 atoms tungstic acid .	37·5
1 atom protoxide of lead	14
	51·5

12. Acetate of lead. The constituents of this salt have been stated in a former part of this work. They are as follows: Acetate,

1 atom acetic acid .	6·25
1 atom protoxide of lead	14
3 atoms water . .	3·375
	23·625

13. Diacetate of lead. This salt was obtained by boiling crystals of acetate of lead and litharge, mixed each in the requisite proportions in a sufficient quantity of distilled water. The litharge was entirely dissolved; and, by evaporating the solution in a gentle heat, the diacetate was deposited in the state of a beautiful white sediment, which had the aspect of crystals, although I could not recognise any regular form. It had a sweet and astringent taste, and was soluble in pure water. I dried this salt, by pressing it between folds of blotting paper, till it ceased to give out any moisture. 45·5 grains of the matter thus treated being subjected to a red heat in a platinum crucible, left 27·9 grains of fused protoxide of lead. From this experiment I consider the constituents of the salt to be Diacetate,

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1 atom acetic acid .	6·25
2 atoms protoxide of lead	28
10 atoms water . .	11·25
	45·5

Trisacetate, 14. Trisacetate of lead. This salt was first obtained by Thenard. His method was to boil 23·625 parts of crystallized acetate of lead with 35·44 parts of litharge, deprived of its carbonic acid by heat. The liquid thus obtained when evaporated deposited the trisacetate in white plates. It is still soluble in water, but less so, and has a less sweet taste, than common acetate of lead. I have not myself made any experiments on this salt; but Berzelius analyzed it, and found its constituents

Acetic acid .	6·25
Protoxide of lead	41

Three atoms of protoxide of lead weigh 42. Hence it is obvious, that the salt was a compound of 1 atom acid and 3 atoms protoxide of lead. If any confidence can be put in Thenard's analysis, it contains 2 atoms water.

Benzoate, 15. Benzoate of lead. This salt forms crystals of a brilliant white colour, soluble both in water and alcohol. From the analysis of Berzelius, its constituents are

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1 atom benzoic acid .	15
1 atom protoxide of lead	14
1 atom water . .	1·125
	30·125

16. Succinate of lead forms long slender crys- Succinate, tals, scarcely soluble in water. They seem to be anhydrous, and are composed of

1 atom succinic acid .	6·25
1 atom protoxide of lead	14
	20·25

17. Formate of lead. This salt is composed of Formate.

1 atom formic acid .	4·625
1 atom protoxide of lead	14
1 atom water . .	1·125
	19·75

18. Oxalate of lead. This salt is an insoluble Oxalate, and tasteless anhydrous powder, composed of

1 atom oxalic acid .	4·5
1 atom protoxide of lead	14
	18·5

19. The same observations apply to tartrate Tartrate, of lead, the constituents of which are

1 atom tartaric acid .	8·25
1 atom protoxide of lead	14
	22·25

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From the preceding details we see that the greater number of the salts of lead are anhydrous; and the few which contain water seldom have more than 1 or 2 atoms in the integrant particle of salt. The acetate of lead is the salt which contains most water. The quantity amounts to 3 atoms to the integrant particle of acetate, while the diacetate (if we suppose it sufficiently dried) contains 10 atoms.

17. SALTS OF COPPER.

The black oxide of copper alone seems capable of combining with acids and forming salts; for, except the protomuriate, we do not know any salt of copper containing the suboxide for a base. From the composition of the salts of copper, there can be no reason to doubt that 5 represents the atomic weight of black oxide of copper.

Sulphate, 1. Sulphate of copper. This well known and beautiful salt has been often described. It always reddens vegetable blues, however carefully prepared; and by long boiling its aqueous solution with peroxide of copper in the requisite proportion, we form an insoluble sulphate of copper, containing twice as much oxide united to the acid as in the soluble salt. It must therefore be a disulphate. Sulphate of copper is composed of

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1 atom sulphuric acid	5
1 atom peroxide of copper	5
5 atoms water . .	5·625
	15·625

2. Nitrate of copper. This is also a well known and beautiful salt. It is so deliquescent, that it is not easy to obtain it in well defined crystals. Its constituents are Nitrate,

1 atom nitric acid .	6·75
1 atom peroxide of copper	5
7 atoms water . .	7·875
	19·625

3. Carbonate of copper. Of this salt there are three species met with native; namely, the anhydrous carbonate, which has a brown colour; the green carbonate, and the blue carbonate. The constituents of the anhydrous carbonate are as follows: Carbonates,

1 atom carbonic acid .	2·75
2 atoms peroxide .	10
	12·75

It is therefore a dicarbonate.

(2.) The green carbonate of copper constitutes the beautiful ore of copper called malachite. When pure, its constituents are

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1 atom carbonic acid .	2·75
2 atoms peroxide of copper	10
1 atom water . .	1·125
	13·875

(3.) The blue carbonate of copper occurs crystallized in oblique rhombic prisms of a beautiful blue colour. It has been repeatedly analyzed. I shall take the experiments of Mr. Phillips as sufficiently exact to show the constituents of this rather complicated salt. He found 100 parts of the crystals composed of

Peroxide of copper	69·08
Carbonic acid	25·46
Water	5·46
	100·00 *

Now, if we consider the salt as composed of

2 atoms carbonate of copper	15·5
1 atom protohydrate of copper	6·125
	21·625

we obtain the following for its constituents per cent.

Peroxide of copper	69·364
Carbonic acid	25·433
Water	5·203
	100

* Institution Journal, IV. 276.

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which corresponds so nearly with the result obtained by Mr. Phillips that there seems no reason to doubt that the salt is really a compound of 2 atoms anhydrous carbonate, and 1 atom of protohydrate of copper.

We see from this native mineral that the oxide of copper and carbonic acid are capable of combining atom to atom; although hitherto chemists have not succeeded in forming any such compounds artificially.

4. Phosphate of copper. This salt, though very rare, is occasionally met with in small dark green crystals, and two species have been recognized by mineralogists; viz. the anhydrous phosphate and the hydrous. The primary form of the first species is considered by Mr. Brooke as a right rhombic prism, while Mr. Levy has shown that the primary form of the other is an oblique rhombic prism. Phosphates,

From the analysis of Mr. Lunn, it appears that the anhydrous phosphate is composed of

1 atom phosphoric acid	3·5
1 atom oxide of copper	5
	8·5

We have no good analysis of the native hydrous phosphate; but Chenevix has given us an analysis of the artificial phosphate, and from his result it appears to be a compound of

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1 atom phosphoric acid	3·5
1 atom peroxide of copper	5
1 atom water	1·125
	9·625

His water exceeded an atom by one third; but as the salt was in the state of powder, this surplus was no doubt mechanical.

Arseniates, 5. Arseniate of copper. This salt has been met with in considerable quantity in Huel Garland copper mine, in the parish of Gwennap, Cornwall. It was analyzed by Chenevix, who found it to consist of four different varieties, distinguished also by the shape of the crystals and the colour. He formed, likewise, an arseniate of copper differing from any of these four varieties, by mixing solutions of arseniate of ammonia and nitrate of copper together, filtrating the mixture, and adding alcohol to the liquid which passed through the filter: rhomboidal crystals of a blue colour gradually precipitated.

These analyses were made at a time when the data were not quite so accurate as at present, and no modern chemist has had it in his power to repeat them. But I think it probable, from Mr. Chenevix's analyses, that these five kinds of arseniates were composed as follows:

(1.) Artificial arseniate,

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1 atom arsenic acid	7·75
1 atom oxide of copper	5
4 atoms water	4·5
	17·25

(2.) The second variety of Chenevix is usually called copper mica. It has a deep emerald green colour, a specific gravity of 2·548, and is crystallized in six-sided plates. Its primary form is an acute rhomboid. It is a subsesquarseniate, being composed of Sesquarseniate,

1 atom arsenic acid	7·75
1½ atom oxide of copper	7·75
3 atoms water	3·375
	18·875

(3.) The third variety of Chenevix is usually called *olivenerz* from its colour, which is a dark or olive green. Its specific gravity is 4·280, and its primary form a right rhombic prism; it consists of

1 atom arsenic acid	7·75
2½ atoms oxide of copper	12·5
6 atoms water . .	6·75
	27·00

(4.) The fourth variety of Chenevix is usually in capillary crystals; its primary form is an oblique rhomb—its colour and specific gravity the same as the preceding. Its composition is also

the same as the preceding, only it contains but half as much water.

1 atom arsenic acid	7·75
2½ atoms oxide of copper	12·5
3 atoms water . .	3·375
	23·625

(5.) The fifth variety of Chenevix is the *linzenerz* of mineralogists. It has a fine grass green colour, a specific gravity of 2·881, and its primary form is an obtuse octahedron with a rectangular base; it contains twice as much base and thrice as much water as the third variety of Chenevix, being composed of

1 atom arsenic acid	7·75
5 atoms oxide of copper	25
18 atoms water . .	20·25
	53

In this last salt, however, the water found by Chenevix approaches nearer to 17 than to 18 atoms.

Chromate, 6. Chromate of copper. This salt was obtained by mixing together solutions of chromate of potash and muriate of copper. A fine buff coloured precipitate with a shade of dark red fell, which was collected on a filter, washed and dried in the open air at a temperature of between 70° and 80°. This powder appeared at

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first tasteless, but it left a slightly sweetish impression, which was followed by a feeling of bitterness. It was not absolutely insoluble in water: for the water used for washing it always came through slightly coloured, though I continued to wash it for several days. It does not affect vegetable blues. 13·9 grains of this powder when exposed to a red heat lost 2·4 grains of its weight; hence, its constituents are

1 atom chromic acid	6·5
1 atom oxide of copper	5
2 atoms water	2·25
	13·75

7. Acetate of copper. This salt has a fine green colour, and crystallizes in large octahedrons with a rhomboidal base. Mr. R. Phillips found that 100 parts of this salt contain 39·5 of oxide of copper. And Berzelius' experiment, when properly corrected, exactly agrees with this statement.* Hence, the constituents of the salt must be Acetate,

Acetic acid	49·375	or	6·25
Oxide of copper	39·5	-	5
Water	11·125	-	1·408
	100		

1·408 exceeds 1 atom of water by 0·283, or

* Annals of Philosophy, (second series) VIII. 192.

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about ¼th of an atom, doubtless owing to the presence of a little hygrometrical water. It is obvious, then, that the constituents of the salt are

1 atom acetic acid .	6·25
1 atom oxide of copper	5
1 atom water . . .	1·125
	12·375

Diacetate, 8. The pigment called *verdigris*, occurs sometimes of a green colour and sometimes of a blue. From the analysis of Mr. Phillips, with which that of Berzelius corresponds, we find it a compound of

1 atom acetic acid .	6·25
2 atoms oxide of copper	10
6 atoms water . .	6·75
	23

Berzelius extracted from verdigris, or *diacetate of copper*, as it may be called, two different salts, the one soluble in water, the other insoluble.

Subsesquacetate, 9. The soluble salt was obtained by evaporating a solution of verdigris in distilled water by a very gentle heat, until the greater part of its saline contents were deposited: by applying heat the whole was dissolved, and the solution was mixed with alcohol. In about an hour a bulky gelatinous looking mass was deposited, consist-

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ing of an aggregation of minute crystals; these were collected on a linen cloth and thoroughly washed; when dry they had rather a pale blue colour. 100 parts of this salt, when kept for some hours in the temperature of 140°, lost, in different trials, 9·5, 10, and 10·3 of its weight: the residue, which had acquired a greenish tint, was boiled for an hour with hydrate of barytes. The filtered liquid, being freed from its excess of barytes by a current of carbonic acid gas, was evaporated to dryness, redissolved and thrown down by sulphuric acid: the sulphate of barytes weighed 84, equivalent to 35·593 of acetic acid. The copper precipitated by iron was ignited in a current of common air, and then reduced by hydrogen gas: it gave 34·352 copper, equivalent to 42·937 oxide of copper. In other experiments he obtained 86·6 and 86·8 sulphate of barytes, equivalent to 43·3 and 43·4 oxide of copper. Hence, the constituents of the salt are

Acetic acid	35·593	or	6·25
Oxide of copper	43·212	-	7·588
Water . .	21·195	-	3·721
	100·000		

6·25 represents an atom of acetic acid, 7·588 differs little from 7·5, an atom and a half of oxide of copper and 3·721 is not quite a third of an atom more than 3·375, which represents 3 atoms of water. Hence, the constituents of the salt are

1 atom acetic acid .	6·25
1½ atom oxide of copper	7·50
3 atoms water . .	3·375
	17·125

It is, therefore, a subsesquacetate of copper.

Trisacetate, 10. The insoluble salt is obtained by allowing verdigris to swell up in water, filtering through coarse linen, which retains the impurities, and lets the salt pass through. The crystalline scales are now separated by pouring the whole of the filtered solution on fine cambric;—they should be pressed closely together and washed a few times with water; after this they must be transferred to a paper filter and thoroughly washed with alcohol. When thus obtained, the salt constitutes a mass of small light blue shining crystalline scales, having a deeper and purer blue colour than the subsesquacetate of copper. When dried in 212°, it loses a very little hygroscopic water, and does not alter its apppearance. From 100 parts of this salt Berzelius obtained 64·25, and in another experiment 64·7 parts of oxide of copper: the acetic acid determined, as in the preceding salt, amounted to 26·995 per cent. Hence, the constituents of the salt are

Acetic acid	26·995	or	6·25
Oxide of copper	64·475	-	14·928
Water . .	8·580	-	1·975
	100·000		

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14·928 is very nearly 15, or 3 atoms of oxide of copper; and 1·975 wants a very little of 2·25; this deficit was probably owing to the previous exposure of the salt to a heat of 212°. The constituents are obviously

1 atom acetic acid .	6·25
3 atoms oxide of copper	15
2 atoms water .	2·25
	23·5*

This salt, is therefore, a trisacetate of copper.

11. Berzelius obtained another insoluble acetate of copper by heating a dilute solution of subsesquacetate of copper. The salt is deposited in liver brown flocks, which become black when collected on the filter and dried. 100 parts of this salt, previously dried in the temperature of 150°, gave from 91·6 to 92·5 of oxide of copper; and the acetic acid, determined by means of hydrate of barytes, was 2·392 per cent. Hence, the constituents of the salt are

Acetic acid .	2·392	or	6·25
Oxide of copper	92·050	-	240·51
Water . .	5·558	-	14·522
	100·000		

240·51 corresponds very nearly with 240, or 48 atoms oxide of copper; and 14·522 differs but

* Annals of Philosophy, (second series) VIII. 195.

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little from 14·625, or 13 atoms of water. Hence, the constituents of the salt are

1 atom acetic acid .	6·25
48 atoms oxide of copper	240·00
13 atoms water . .	14·625
	260·875

unless we be rather disposed to consider it as a mechanical mixture of oxide of copper and a little trisacetate of copper;—this I think the most probable supposition.

Oxalate, 12. Oxalate of copper. This is a green tasteless insoluble powder, which, when dried in the open air, is a compound of

1 atom oxalic acid .	4·5
1 atom oxide of copper	5
1 atom water . .	1·125
	10·625

One half of the water is very easily expelled by heat; but the remainder continues obstinately fixed till the acid undergoes decomposition.

Tartrate, 13. Tartrate of copper. This salt is easily formed by mixing dilute solutions of sulphate of copper and tartrate of potash. Small green crystals by degrees form, which are very little soluble in water. The constituents of this salt are

1 atom tartaric acid .	8·25
1 atom oxide of copper .	5
3 atoms water . .	3·375
	16·625

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14. Formate of copper. This salt has a greenish blue colour, and forms flat six-sided prisms terminated by four-sided pyramids. Its constituents, from Berzelius' analysis, appear to be Formate.

1 atom formic acid .	4·625
1 atom oxide of copper	5
4 atoms water . .	4·5
	14·125

From the preceding list, which includes a considerable number of native cupreous salts, it appears that most of the salts of this genus contain water of crystallization. In general the quantity of water is small, for more than half the salts in the list contain only 1, 2, or 3 atoms. One of the carbonates and one of the phosphates are anhydrous—green dicarbonate, a phosphate, acetate, and oxalate, contain 1 atom—chromate and trisacetate contain 2 atoms—two arseniates, subsesquacetate and tartrate, 3—an arseniate and formate 4—sulphate 5—an arseniate and verdigris 6—nitrate 7—an arseniate 18. With the exception of this last arseniate, 7 is the greatest number of atoms of water in any cupreous salt hitherto analyzed.

18. SALTS OF BISMUTH.

1. Sulphate of bismuth. This salt is usually in the state of a white powder, though it may be Sulphate,

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obtained also in needles. It is usually anhydrous, and consists of

1 atom sulphuric acid	5
1 atom oxide of bismuth	10
	15

Nitrate. 2. Nitrate of bismuth. This salt may be obtained from a solution of the salt, formed by dissolving bismuth in nitric acid in water, by evaporating the solution. It forms very beautiful transparent colourless crystals having the shape of pretty oblique rhombs.

The constituents of these crystals are

1 atom nitric acid .	6·75
1 atom oxide of bismuth	10
3 atoms water . .	3·375
	20·125

Dinitrate. 3. Dinitrate of bismuth. The crystals that form when bismuth is dissolved in rather concentrated nitric acid, have an excess of acid from which they may be freed by pressure between folds of blotting paper. I analyzed them thus purified as much as possible, and found the constituents

1 atom nitric acid .	6·75
2 atoms oxide of bismuth	20
2 atoms water . .	2·25
	29

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4. Carbonate of bismuth. This salt was obtained by decomposing nitrate of bismuth by an alkaline carbonate. The white precipitate, being collected on a filter, washed, and dried, was a white tasteless powder, quite insoluble in water. Carbonate,

100 grains of it being dissolved in nitric acid, the loss of weight was 7·5 grains. 100 grains of the same salt were gradually heated to redness in a platinum crucible, the oxide remaining was partially fused, and the loss of weight was 13·8 grains. Hence, the constituents of this salt are

Carbonic acid	7·5	or	2·75
Oxide of bismuth	86·2	-	31·606
Water	6·3	-	2·31
	100·0		

From this analysis there can be little doubt that the constituents of this salt are

1 atom carbonic acid	2·75
3 atoms oxide of bismuth	30
2 atoms water	2·25
	35

It is therefore a triscarbonate. The small excess of oxide observable in the analysis, was probably mechanically mixed with the salt, and the very slight excess of water was undoubtedly hygrometrical.

5. Phosphate of bismuth. This salt was obtained by adding as much nitric acid to a solu- Phosphate,

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tion of nitrate of bismuth as prevented the salt from being thrown down by water. Phosphate of soda being poured into this solution, a white precipitate fell, which was phosphate of bismuth. When collected on the filter, washed, and dried in the open air, it constituted a white tasteless powder, insoluble in water, and apparently neutral; 5·22 grains of this salt when exposed to a red head did not melt, but lost 1 grain of moisture. Hence, its constituents are

Anhydrous phosphate	4·22	or	13·5
Water . .	1	-	3·199
	5·22		

I consider its constituents to be

1 atom phosphoric acid	3·5
1 atom oxide of bismuth	10
3 atoms water . .	3·375
	16·875

Arseniate, 6. Arseniate of bismuth. This salt was formed by the same process as the last, merely substituting arseniate of soda for phosphate of soda. When the arseniate of bismuth was collected on the filter, washed, and dried in the open air, it constituted a white powder with a slight shade of yellow. It was tasteless and insoluble in water, and did not alter vegetable blues; hence, I consider it as a neutral salt. 19·75 grains of

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it, when exposed to a red heat, underwent no apparent change, but lost 2·01 grains of weight. Hence, I am disposed to consider the salt as composed of

1 atom arsenic acid	7·75
1 atom oxide of bismuth	10
2 atoms water . .	2·25
	20

7. Chromate of bismuth. This salt was formed in the same way as the two last, chromate of potash being substituted for phosphate of soda. When collected on the filter, washed, and dried, it constituted a fine yellow tasteless powder, insoluble in water, and not altering vegetable blues. 18·86 grains of this salt being heated to redness, did not melt, but lost its fine yellow colour, and became light yellowish brown. The loss of weight was 2·364 grains. Hence, the constituents of the salt must be Chromate,

1 atom chromic acid .	6·5
1 atom oxide of bismuth	10
2 atoms water . .	2·25
	18·75

8. Oxalate of bismuth. This salt was formed in the same way as the preceding one, substituting oxalate of ammonia for chromate of potash. When collected on the filter, washed, and dried Oxalate,

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in the open air, it is a fine white tasteless powder, insoluble in water, and producing no change on vegetable blues. 14·89 grains of this salt, exposed to the greatest heat of the sand bath, gave out water, and lost 0·39 grain of weight. This was water mechanically lodged. The salt is anhydrous, and composed of

1 atom oxalic acid .	4·5
1 atom oxide of bismuth	10
	14·5

Tartrate, 9. Tartrate of bismuth. Formed in the same way—a fine white tasteless insoluble powder. 23·7 grains when heated on the sand bath gave out 5·45 grains water: hence, the constituents are

1 atom tartaric acid .	8·25
1 atom oxide of bismuth	10
5 atoms water . .	5·625
	23·875

The salts of bismuth, if any consequences can be drawn from the preceding list, seem in general to contain 2 or 3 atoms of water. Two of the salts, the sulphate and oxalate, are anhydrous—four, the dinitrate, carbonate, arseniate, and chromate, contain 2 atoms—two, the nitrate and phosphate, contain 3 atoms, while the tartrate contains 5 atoms.

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19. SALTS OF MERCURY.

Both of the oxides of mercury combine with acids and form salts, several of which are capable of crystallizing.

(1.) PROTOSALTS.

1. Protosulphate of mercury. This salt is formed when sulphuric acid is heated on mercury. Sulphurous acid exhales, and protosulphate of mercury is gradually deposited in fine white crystals. When these crystals are washed with a little water they may be dried on blotting paper; in this state they constitute a white salt in scales. It has very little taste, reddens vegetable blues, and when heated on the sand bath the colour becomes darker, the salt assumes a silky lustre, and the scaly structure is much more conspicuous. 32·725 grains heated on the sand bath lost 1·725 grain. Probably the constituents are Protosulphate,

1 atom sulphuric acid .	5
1 atom protoxide of mercury	26
2 atoms water . . .	2·25
	33·25

2. Nitrate of mercury. This salt is easily obtained by dissolving in nitric acid of the specific gravity 1·42, as much mercury as it will take Nitrate,

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up: the quantity exceeds twice the weight of the acid—heat is produced during the solution—the liquid is transparent and colourless like water; on cooling, it deposites a very considerable number of white crystals, which constitute the salt in question. I have not myself been able to determine the shape of these crystals; but they are said to be octahedrons with their apexes truncated. I have always obtained them in prisms, seemingly four-sided. This salt is not altered by exposure to the air; it has the disagreeable taste which distinguishes the soluble mercurial salts. When digested in water, it dissolves only partially, leaving a green powder which is a subnitrate of mercury; but it dissolves with facility in water acidulated with nitric acid. 50 grains of this salt were decomposed by caustic potash. The protoxide of mercury (not quite free from peroxide) weighed 37·6 grains. Now, as the atomic weight of protoxide of mercury is 26, we have 26 : 6·75 : : 37·6 : 9·76 = nitric acid of the salt. 50 — 37·6 = 12·4, and 12·4 — 9·76 = 2·64, the water contained in 50 grains of the salt. Hence, the constituents ought to be

Nitric acid .	9·76	or	6·75
Protoxide of mercury	37·60	-	26
Water . .	2·64	-	1·825
	50		

The water amounts to 1⅛ atom. As the oxide

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of mercury was mixed with some peroxide, I am disposed to consider the salt as a compound of

1 atom nitric acid .	6·75
1 atom protoxide of mercury	26
2 atoms water . .	2·25
	35

I attempted to determine the quantity of nitric acid in 50 grains of this salt by means of carbonate of barytes, and by means of ammonia; but neither of the results was satisfactory.

M. Grouvelle has examined the diprotonitrate of mercury, obtained by decomposing the protonitrate, by means of water, and shown it to be a compound of

1 atom nitric acid .	6·75
2 atoms protoxide of mercury	52
	58·75

It contains no water.*

3. Protocarbonate of mercury. This salt was obtained by precipitating a solution of nitrate of mercury by carbonate of soda. It is a white, tasteless powder, insoluble in water. 41·4 grains of it were dissolved in nitric acid in a small two mouthed phial, previously accurately poised in a balance; the loss of weight was 6 grains, or Protocarbonate,

* Ann. de Chim. et de Phys. XIX. 139.

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rather 5·98 grains. Now, 35·4 : 6 : : 26 : 4·406 = carbonic acid united to 26 grains of protoxide of mercury. 4·406 approaches so near 4·125, which is equivalent to an atom and a half of carbonic acid, that there seems no doubt that the salt was a sesquicarbonate, composed of

1½ atom carbonic acid .	4·125
1 atom protoxide of mercury	26
	30·125

Protophosphate,

4. Protophosphate of mercury. This salt was obtained by decomposing nitrate of mercury by phosphate of soda. It is a white tasteless powder, insoluble in water. From 96·2 grains of nitrate of mercury I got 85·3 grains of phosphate of mercury; the phosphate, after being dried in the open air, lost scarcely any weight on the sand bath. From this it is obvious, that the phosphate of mercury is anhydrous, and the weight of the salt from 96·2 of nitrate shows that it is composed of

1 atom nitric acid .	6·75
1 atom protoxide of mercury	26
	32·75

Protarseniate,

5. Protarseniate of mercury. It is obtained when arseniate of soda is poured into a solution of protonitrate of mercury. It is a grey powder, destitute of taste, and insoluble in water. As it

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loses no weight when heated on the sand bath, it is anhydrous, and is composed of

1 atom arsenic acid .	7·75
1 atom protoxide of mercury	26
	33·75

6. Protochromate of mercury. This is a fine red coloured insoluble powder, obtained by mixing together solutions of protonitrate of mercury and chromate of potash. 50 grains of this salt dried in the open air, were digested in a solution of caustic potash; the protoxide of mercury was separated in the state of a black powder, which, dried in a gentle heat, weighed 38·57 grains. The potash liquid assumed a yellow colour; it was neutralized by nitric acid, and mixed with a solution of nitrate of lead till the whole chromic acid was thrown down. The chromate of lead dried on the sand bath weighed 31·57 grains, equivalent to 10·01 grains of chromic acid. Thus it appears, that the constituents of the salt are Protochromate,

Chromic acid	10·01	or	6·5
Protoxide of mercury	38·57	-	25·05
Water	1·42	-	0·922
	50·00		

The water being less than an atom, it is obvious that the salt is anhydrous, and that the small

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quantity of moisture present is merely hygrometrical. Doubtless the true constituents of this salt are

1 atom chromic acid	6·5
1 atom protoxide of mercury	26
	32·5

The reason why the weight of the protoxide of mercury appears less than the truth, is that a certain portion of it was reduced to the metallic state during the drying. This likewise increased the apparent quantity of water, by occasioning a loss.

Protacetate,

7. Protacetate of mercury. This salt is immediately deposited in beautiful silky scales, when solutions of nitrate of mercury and acetate of soda are mixed together. It has the disagreeable taste of the mercurial salts; but it is the least soluble of all the acetates, requiring about six hundred times its weight of water to dissolve it. On this account, nitrate of mercury may be employed as a good reagent to discover the presence of acetic acid in saline solutions. If the quantity of acetic acid present exceed $\frac{1}{600}$th of the weight of the liquid, the silvery scales of acetate of mercury almost always present themselves. 10 grains of these scales being digested in a flask with caustic potash gave 6·98 grains of protoxide of mercury; hence, the acid and water in these 10 grains amounted to 3·02

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grains. But 26 : 6·25 : : 6·98 : 1·678 = acid in the 10 grains of salt: And 3·02 — 1·678 = 1·342 = water in the 10 grains. Hence, the constituents are

Acetic acid	1·678	or	6·25
Protoxide of mercury	6·98	-	26
Water	1·342	-	4·99

From this it follows, that the constituents of the salt are

1 atom acetic acid	6·25
1 atom protoxide of mercury	26
4 atoms water . .	4·5
	36·75

The excess of water in the experimental result is owing to the cause pointed out, while giving an account of the constituents of protochromate of mercury.

8. Protoxalate of mercury. This salt may be easily obtained by mixing together solutions of nitrate of mercury and oxalate of ammonia. It precipitates in the state of a white powder, which is nearly tasteless and insoluble in water. When dried in a heat of about 100°, it is a beautiful white powder, which when placed on the sand bath gives out a little water; it then explodes with considerable violence. In consequence of this property I did not succeed in determining the water of crystallization. But Protoxalate,

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judging from the quantity of water actually given out, I consider the constituents to be

1 atom oxalic acid	4·5
1 atom protoxide of mercury	26
1 atom water	1·125
	31·625

Prototartrate,

9. Prototartrate of mercury. This salt precipitates when tartrate of potash is mixed with solution of protonitrate of mercury. The precipitate, when it first falls, is snow white; but in a few minutes it blackens considerably, and, when collected on the filter, washed and dried in the open air, it is grey. It has scarcely any taste, and does not appear soluble in water. 50 grains of this salt were exposed in a platinum crucible on the sand bath. No water was exhaled; but the salt blackened, in consequence of the decomposition of the tartaric acid, and lost 1·9 grain of its weight. From this experiment I consider the salt as anhydrous, and composed of

1 atom tartaric acid	8·25
1 atom protoxide of mercury	26
	34·25

From the preceding list of the protosalts of mercury it appears that, as far as their water of crystallization is concerned, they bear a great resemblance to the salts of lead. Most of them

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are anhydrous, and the rest contain 1, 2, or 4 atoms of water.

Six species, viz. Diprotonitrate, protocarbonate, protophosphate, protarseniate, protochromate, and prototartrate, are anhydrous—one, the oxalate, contains 1 atom water—two, the protosulphate and protonitrate, contain 2—and one, protacetate, contains 4.

(2.) PERSALTS OF MERCURY.

1. Persulphate of mercury. This salt, according to the observations of Fourcroy, which are to a considerable extent correct, exists in various states; but the neutral salt is the beautiful yellow powder, known by the name of turpeth mineral, or queen's yellow. It is a tasteless insoluble powder, the constituents of which are Persulphate,

1 atom sulphuric acid .	5
1 atom peroxide of mercury	27
	32

2. Bipersulphate of mercury. In white irregular crystals. I found them composed of Bipersulphate,

2 atoms sulphuric acid .	10
1 atom peroxide of mercury	27
1 atom water . .	1·125
	38·125

3. Pernitrate of mercury. This is a beautiful Pernitrate,

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transparent and colourless salt, which crystallizes in rhombic prisms, with angles of about 74° and 106°. I formed it by accident some years ago. When thrown into water it is decomposed, peroxide of mercury remaining. When heated, it becomes first opaque, then yellow, and is at last dissipated. Its constituents are as follows :

1 atom nitric acid .	6·75
1 atom peroxide of mercury	27
	33·75

Dipernitrate. 4. Dipernitrate of mercury. This salt was examined by M. Grouvelle, who informs us that it is anhydrous, and composed of

1 atom nitric acid .	6·75
2 atoms peroxide of mercury	54
	60·75 *

20. SALTS OF SILVER.

The only good solvent of silver is nitric acid. The combinations of the oxide of silver, with most of the other acids, are insoluble in water, or at least require a great deal of that liquid to dissolve them.

Nitrate, 1. Nitrate of silver. This well known and beautiful salt crystallizes in rhombs, which are usually flat; and the angles of the large face,

* Ann. de Chim. et de Phys. XIX. 140.

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measured as carefully as possible with the common goniometer, are 70° 37′, and 109° 23′. The usual plates in which its crystals appear, if attentively examined, show clearly enough that the shape is rhomboidal, and the angles of the larger faces may easily be observed; but, by spontaneous crystallization, I have obtained large and very regular crystals—though the faces were not smooth enough to admit of measurement by the reflecting goniometer. The properties of this salt are sufficiently known. It dissolves in its own weight of cold water, and in about four times its weight of alcohol. Its taste is exceedingly acrid, and it constitutes a violent poison. When heated it melts, and, on cooling, congeals into a mass of a grey colour, and composed of small needle-form crystals. In this state it is used by surgeons as an escharotic, under the name of *lunar caustic*. I have never yet met with lunar caustic, as it is prepared for sale, absolutely pure. It always contains some gold, and often a little copper. Both of these metals separate in dark flocks when the caustic is dissolved in water. Not unfrequently it contains nitrate of potash; and perhaps there may be other occasional impurities, which I have not detected. This salt is anhydrous, both when crystallized and in the state of lunar caustic. 21·5 grains of the crystals, dried upon blotting paper, when kept for 20 minutes in a state of fusion in a platinum cru-

cible, lost 0·201 grain of water. This is somewhat less than $\frac{1}{3}$th of an atom, and was doubtless lodged mechanically between the plates of the crystals. The constituents of nitrate of silver are

1 atom nitric acid .	6·75
1 atom oxide of silver .	14·75
	21·5

Sulphate,

2. Sulphate of silver. I obtained this salt both by digesting sulphuric acid over oxide of silver, and by mixing together concentrated solutions of nitrate of silver and sulphate of soda. The salt falls in the state of a white powder, which may be dissolved in about 88 times its weight of boiling water. When the solution cools the salt is partly deposited in the state of small needles. This salt has the peculiarly disagreeable taste which characterizes all the soluble salts of silver. Sulphate of silver melts when exposed to a moderate heat; and if the temperature be raised, the oxide is reduced to the metallic state. The salt is anhydrous; for, 19·82 grains of it, being heated on the sand bath till it became yellow, and consequently till it began to be decomposed, lost 0·07 grain of its weight. Now, this quantity, supposing it all water, would amount only to rather less than $\frac{1}{10}$th of an atom. The constituents of the salt are

1 atom sulphuric acid	5
1 atom oxide of silver	14·75
	19·75

3. Carbonate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver, and an alkaline carbonate. It constitutes a white insoluble powder, with a slight shade of blue. When this salt is mixed with dilute nitric acid, a pretty rapid effervescence takes place, owing to the escape of the carbonic acid gas, and a colourless solution is obtained. I found that 38·7 grains of carbonate of silver yielded 47·87 grains of fused nitrate of silver. This is equivalent to 32·841 grains of oxide of silver. Now, 14·75 : 2·57 : : 32·841 : 6·122 = carbonic acid united to the oxide of silver. But, 32·841 + 6·122 = 38·963, which rather exceeds the weight of carbonate of silver employed. It is obvious from this that the salt is anhydrous, and that its constituents are Carbonate,

1 atom carbonic acid	2·75
1 atom oxide of silver	14·75
	17·5

4. Phosphate of silver. When nitrate of silver and phosphate of soda are dissolved in separate portions of water, and the solutions are mixed, there falls down a fine yellow coloured precipi- Phosphate,

tate, which is phosphate of silver. This powder is insoluble in water; but not quite destitute of the peculiar taste which characterizes the salts of silver. 43 grains of anhydrous nitrate of silver were mixed with a solution of 42 grains of phosphate of soda. The yellow coloured precipitate, when washed and dried on the filter, weighed 27·74 grains. When exposed to heat on the sand bath, it gave out no water, and did not lose any sensible weight. A little carbonate of soda being dropt into the liquid from which the yellow precipitate fell, a new portion of yellow precipitate appeared, which, being collected on a filter, washed, and dried, weighed 8·5 grains. It was rather paler coloured than the first precipitate, but in other respects similar. It was also anhydrous.

Thus, the precipitate from 43 grains of nitrate of silver weighed 36·24 grains; it lost, when heated to redness, 0·624 grain, and was reduced to 35·616 grains; it contained all the oxide of silver in 43 grains of nitrate, or 29·5 grains—the remainder of the weight consisted of phosphoric acid. Hence, the phosphate of silver obtained in this way, was composed of

Oxide of silver	.	29·5	or 14·75
Phosphoric acid	.	6·116	- 3·058

14·75 is the weight of an atom of oxide of silver,

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and 3·058 is not quite $\frac{1}{7}$th less than the weight of an atom of phosphoric acid. It is obvious that neutral phosphate of silver is composed of

1 atom phosphoric acid	3·5
1 atom oxide of silver	14·75
	18·25

There was an excess of oxide in the salt which I obtained; for that salt was composed of

1 atom phosphoric acid	3·5
1 atom oxide of silver	14·75 + 2·13

This surplus amounts nearly to $\frac{1}{7}$th part, which I consider as too small to constitute an atomic addition.

When the yellow phosphate of silver is digested in phosphoric acid, we obtain a white salt, which I have not analyzed, but which is certainly either a neutral phosphate or a biphospate of silver,—probably the latter.

If we were to suppose the yellow phosphate of silver a mixture of 6 atoms neutral phosphate of silver and 1 atom diphosphate of silver, we would obtain very nearly the same constituents that I procured. For

6 atoms phosphate of silver weigh	Phosphoric acid	21	109·5
	Oxide of silver	88·5	
1 atom diphosphate	Acid . .	3·5	33
	Oxide . .	29·5	

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So that the oxide amounts to . . .	118
And the acid to	24·5

Now, $\frac{24·5}{7} = 3·5$, and $\frac{118}{7} = 17$, which approaches very nearly to 16·88, the quantity of silver contained in the salt which I examined.

Arseniate, 5. Arseniate of silver. When solutions of nitrate of silver and arseniate of soda are mixed together in the atomic proportions, a flesh coloured precipitate falls in large flocks. This precipitate is arseniate of silver; it is tasteless, or nearly so, and is insoluble in water. When dried it becomes reddish brown; when heated to redness it becomes nearly black; and 84·4 grains, when thus treated, lost 0·5 grain of water, which was obviously merely lodged mechanically in the powder. By this treatment the powder assumes nearly a black colour.

43 grains of anhydrous nitrate of silver were dissolved in water, and mixed with a solution of 41·5 grains of the crystals of arseniate of soda: the flesh red powder which precipitated being collected, washed, and dried on the filter, weighed 37·75 grains. Ammonia being poured into the residual liquid an additional flesh red precipitate fell, which weighed, when dry, 2 grains; so that the whole arseniate of silver obtained from 43 grains of nitrate of silver was 39·75 grains; which, by exposure to a red heat, was reduced to 39·22 grains. As it contained all the silver

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in the 43 grains of nitrate it was obviously composed of

Oxide of silver	29·5	or	14·75
Arsenic acid .	9·72	-	4·86
	39·22		

14·75 represents an atom of oxide of silver, but 4·86 is less than an atom of arsenic acid by 2·89, which is rather more than the third of an atom. We see from this, that the arseniate of silver, (like the phosphate) when obtained by precipitation, is not an accurate atomic compound;—it is doubtless a mixture of two or more arseniates in different states of saturation. It is composed of

1 atom arsenic acid .	7·75
1 atom oxide of silver .	14·75 + 8·771

8·771 exceeds half an atom by only 1·396; hence, it is obvious that the greater part of the precipitate is a subsesquarseniate of silver, composed of

1 atom arsenic acid .	7·75
1½ atom oxide of silver	22·125
	29·875

With this subsesquarseniate there is mixed a small portion of di-arseniate of silver.

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Chromate, 6. Chromate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver and chromate of potash. The chromate of silver falls in the state of a dark red powder, which is insoluble in water, or nearly so, and not altered by exposure to heat. 43 grains of anhydrous nitrate of silver being dissolved in water and mixed with a solution of 25 grains of chromate of potash, the chromate of silver obtained by precipitation, after being washed and dried, weighed 39·67 grains. Carbonate of soda being dropped into the residual liquid a slight additional precipitate was obtained, which weighed very nearly 2¼ grains; so that the whole chromate of silver obtained weighed 42·17 grains. Now, if we suppose it to be a compound of

1 atom chromic acid	.	6·5
1 atom oxide of silver	.	14·75
		21·25

the whole of it would have amounted to 42·5 grains. This approaches so near the quantity actually obtained, that there seems no room for doubting that the correct constituents of the salt are those just stated.

Acetate, 7. Acetate of silver. This salt may be obtained by digesting oxide of silver in acetic acid. The solution is colourless, but yields, by evaporation, white crystals having a silky lustre, and

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the form of long but small four-sided flat prisms. The salt is extremely light, and very sparingly soluble in water.

76 grains of these crystals were digested in nitric acid till the acetic acid was disengaged, and then evaporated to dryness,—the anhydrous nitrate of silver weighed 78 grains. Now, 78 : 21·5 : : 76 : 20·95 = atomic weight of acetate of silver. Hence, its constituents must be

1 atom acetic acid .	6·25
1 atom oxide of silver .	14·75
	21

For the 0·05 wanting was doubtless owing to an error in the experiment. It is obvious from this, that acetate of silver is anhydrous.

8. Oxalate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver, and oxalate of ammonia. It falls down in the state of an exceedingly fine and very white powder, quite different in appearance from chloride of silver. The colour is very apt to become dark when heat is applied, owing probably to a commencement of decomposition ; this salt is scarcely soluble in water. 43 grains of anhydrous nitrate of silver were dissolved in water and mixed with a solution of 17·75 grains of oxalate of ammonia. The precipitate obtained being well washed and dried, weighed 37·86 grains. Carbonate of soda being dropped into Oxalate,

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the residual liquid, a little more oxalate of silver fell, weighing very nearly half a grain. Thus, the whole oxalate of silver obtained from 43 grains of nitrate was 38·36 grains. This is so near 38·5, the quantity which would have been obtained on the supposition that the salt is a compound of an atom of each constituent, that we cannot hesitate about adopting the following as exhibiting its true constitution :

1 atom oxalic acid .	4·5
1 atom oxide of silver .	14·75
	19·25

Oxalate of silver is obviously anhydrous.

Tartrate. 9. Tartrate of silver. When solutions of nitrate of silver and tartrate of potash are mixed together, a fine white powder falls. If we raise the temperature of the liquid a very little, the colour of the precipitate becomes dark brown; indeed, this change takes place spontaneously, if the powder be allowed to remain for twenty-four hours in contact with the liquid from which it was thrown down. When this powder is dried upon the filter it is anhydrous; for 18 grains of it, when heated strongly on the sand bath, became black, gave out no water, but lost 0·5 grain of weight, owing obviously to a commencement of decomposition.

43 grains of nitrate of silver being dissolved in water, and mixed with a solution of 33 grains

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of tartrate of potash, the tartrate of silver precipitated, after being washed and dried, weighed 42·9 grains. Ammonia being dropt into the residual liquid, no immediate change was produced, but after an interval of twenty-four hours the inside of the glass was lined with a deep brown deposite, having a semimetallic lustre, and adhering so firmly to the glass that I could not weigh it with accuracy; but it certainly amounted to 3 grains. From this experiment I consider the tartrate of silver as a neutral salt, composed of

1 atom tartaric acid	8·25
1 atom oxide of silver	14·75
	23

From the preceding detail, we see that all the salts of silver hitherto examined are anhydrous. This is a peculiarity which belongs to no other genus of salts except those of silver.

SECT. II.

OF THE COMPOSITION OF THE COMPOUND SALTS.

Nature of compound salts.

The compounds, usually distinguished by the name of *triple salts*, are formed by the union of two simple salts with each other. These two

salts have in most cases the same acid combined in each with a different base; though there are a few examples of the union of two salts differing from each other both in their acids and bases. There are perhaps, examples likewise of two salts uniting, formed of the same base each, but containing different acids, though I do not at present recollect any such. It is obvious from this account of their constitution, that the term *triple salts* cannot with precision apply to these bodies. The name *double salts*, by which Berzelius distinguishes them, is more correct; though even it may probably be ultimately found rather too limited to include the whole of these saline bodies; perhaps, therefore, it may be better to apply to them the term *compound salts*, by which I have distinguished them in the title affixed to this section.

The compound salts are extremely numerous, much more so, I have reason to believe, than the simple salts. In general they crystallize more readily, and more regularly than the simple salts; many of them are exceedingly beautiful, and such of them as act as purgatives, are both more elegant and more useful medicines than the simple salts from which they were formed; almost all the salts of ammonia and of potash have the property of forming compounds with other simple salts, and constituting compound salts. Soda, and the alkaline earths, do not en-

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ter so readily into these combinations; but a considerable number of compound salts containing these bases are known, and perhaps, if sufficient pains were bestowed upon the investigations, methods might be found of causing the salts of these bases to enter into as many combinations with other salts as the salts of ammonia and potash.

Most commonly the compound salts consist of an integrant particle of each of the simple salts united together; but to this law there are many exceptions. It is not uncommon for three integrant particles of one of the salts to be united with one integrant particle of the other salt. The water of crystallization is seldom the amount of the water in the two salts before combination; most commonly it is less, but in some rare instances considerably greater.

I shall divide this section into three parts. In the first part, I shall exhibit the composition of the compound salts which contain ammonia; in the second, of those which contain potash; and in the third, I shall give the constituents of a few compound salts which contain neither of these bases.

I. OF COMPOUND SALTS CONTAINING AMMONIA.

Ammonio-sulphate of potash.

1. Ammonio-sulphate of potash. This salt may be easily formed by dissolving

1 atom sulphate of potash	= 11
1 atom sulphate of ammonia	= 8·25

or any equimultiples of these weights in water, evaporating the mixed solutions to the crystallizing point. The salt is deposited in small beautiful crystals, which crystallize in four-sided prisms with square bases—taste bitter—specific gravity 2·64. 13·68 grains dissolve in 100 water of temperature 61°. Their constituents are

1 atom sulphate of potash	11
1 atom sulphate of ammonia	7·125
4 atoms water . .	4·5
	22·625

Here the water of crystallization considerably exceeds that of the salts of which it is composed.

Ammonio-sulphate of soda.

2. Ammonio-sulphate of soda. The same process may be followed successfully in forming this salt. The taste of this salt is pungent and bitter. It crystallizes in oblique prisms with rhombic bases.

The crystals are not altered by exposure to the air. Its constituents are

1 atom sulphate of soda	9
1 atom sulphate of ammonia	7·125
6 atoms water . .	6·75
	22·875

In this salt the water of crystallization does not

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much exceed half the quantity contained in the salts before combination; for sulphate of soda contains ten atoms, and sulphate of ammonia one atom of water.

3. Ammonio-sulphate of magnesia. This salt, which may be obtained by the same process as the preceding, crystallizes in beautiful rhomboids, which are not altered by exposure to the air. It has a bitter taste, a specific gravity of 1·721, and its constituents are

Ammonio-sulphate of magnesia.

1 atom sulphate of magnesia	7·5
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	22·5

4. Ammonio-sulphate of alumina. This salt is precisely similar in its appearance and properties to common *alum*. Its crystals are regular octahedrons; its solubility in cold water is rather less than that of alum. I analyzed this salt with much care, and found its constituents

Ammonio-sulphate of alumina.

3 atoms sulphate of alumina	21·75
1 atom sulphate of ammonia	7·125
25 atoms water	28·125
	57

This approaches as near the weight of an integrant particle of common alum as the constituents will admit. The only difference is the sub-

stitution of an atom of sulphate of ammonia for an atom of sulphate of potash.

5. Ammonio-trisulphate of alumina. This salt may be obtained by precipitating a boiling solution of ammoniacal alum by an alkali. It is an insoluble powder, which I have not particularly examined.

Ammonio-persulphate of iron.

6. Ammonio-persulphate of iron. This salt was first prepared by Mr. Cooper, who described it as a simple persulphate of iron; but for our first knowledge of its constituents and its properties we are indebted to Dr. Forchhammer. As soon as I became acquainted with Dr. Forchhammer's experiments,* I examined some of Mr. Cooper's crystals, which he had been kind enough to send me several years ago, and found them to contain abundance of ammonia, and to be in fact the very same triple salt as that described by Dr. Forchhammer.

This salt is easily obtained by mixing together solutions of persesquisulphate of iron and sulphate of ammonia in the proportion of two integrant particles of the former to one of the latter, concentrating the mixture somewhat, and setting it aside. The double salt is deposited in very regular crystals; it is transparent and colourless, and is crystallized in octahedrons precisely similar to those of alum. It is soluble

* Annals of Philosophy (second series) V. 409.

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in about three times its weight of water at 60°; it has a taste very similar to that of alum, and may in fact be considered as an ammoniacal alum, with persulphate of iron substituted for sulphate of alumina. I analyzed it in the same way as soda alum, and found its constituents to be

2 atoms persesquisulphate of iron	25
1 atom sulphate of ammonia	7·125
25 atoms water . . .	28·125
	60·25

It comes therefore as near as possible to the atomical weight of ammoniacal alum. Yet it is not analogous to that alum in its composition: for the alum consists of 3 atoms of sulphate of alumina united to 1 atom of sulphate of ammonia; whereas this salt contains only 2 atoms of sesquisulphate of iron united to 1 atom of sulphate of ammonia. The quantity of sulphuric acid in an integrant particle of both salts is the same, namely 4 atoms; 2 atoms of peroxide of iron are substituted for 3 atoms of alumina.

7. Ammonio-sulphate of nickel. This is a beautiful green coloured salt, crystallized in flat rhombs. It dissolves readily in water, and crystallizes with facility; its specific gravity is 1·801. Its constituents are

Ammonio-sulphate of nickel.

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1 atom sulphate of nickel	9·25
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	24·25

In this salt the water of crystallization is the same as in sulphate of nickel. The sulphate of ammonia is anhydrous.

Ammonio-sulphate of manganese.

8. Ammonio-sulphate of manganese. This salt likewise crystallizes in rhombs, and is very easily obtained by mixing together solutions of the two salts constituting it, in the atomic proportions, and concentrating the mixture. Its specific gravity is 1·93. Its constituents are as follows:

1 atom sulphate of manganese	9·5
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	24·5

So that the water exceeds by 1 atom the water of crystallization in both the constituents.

Ammonio-sulphate of zinc.

9. Ammonio-sulphate of zinc. This salt was obtained by mixing solutions of the two constituent salts in the atomic proportions, and concentrating the solution. It crystallizes in fine white rhomboids, which have the peculiar taste of the zinc salts, and dissolve readily in water. The constituents of this salt are as follows:

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1 atom sulphate of zinc	10·25
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	25·25

Here the sulphate of zinc retains its usual proportion of water, and the sulphate of ammonia unites to it anhydrous.

10. Ammonio-sulphate of copper. The constituents of this salt, according to the analysis of it in my laboratory, are as follows: Ammonio-sulphate of copper.

1 atom sulphate of copper	10
1 atom sulphate of ammonia	7·125
6 atoms water . . .	6·75
	23·875

And this analysis exactly agrees with the statement previously given by Berzelius, that both salts retain their water of crystallization.

11. Ammonio-carbonate of uranium. This beautiful salt has been described in volume II. page 4. of this work. Its constituents were there shown to be Ammonio-carbonate of uranium.

1 atom percarbonate of uranium	30·75
3 atoms carbonate of ammonia	14·625
4 atoms water	4·500
	49·875

So that each integrant particle of salt in the compound retains an atom of water.

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Ammonio-phosphate of soda.

12. Ammonio-phosphate of soda. This salt, which has been so long known under the name of *microcosmic salt*, and is so useful to mineralogists as a flux in experiments made by the blow-pipe, is easily obtained by mixing solutions of phosphate of soda and phosphate of ammonia in the atomic proportions, and concentrating the mixture. The compound salt crystallizes in fine four-sided rectangular prisms, terminated by rectangles; the solution yields these crystals to the very last drop, showing that the salt contains just an integrant particle of each constituent. It has a saline and cooling taste, and dissolves with facility in water; when heated it melts in its water of crystallization; if the heat be continued the water is dissipated; in a red heat the ammonia likewise escapes, leaving biphosphate of soda, which melts into a transparent glass, dissolves in water, and reddens vegetable blues. 20 grains of the crystals of this salt, when thus treated, lose 13 grains of their weight. Now, 11 is the atomic weight of anhydrous biphosphate of soda; and 7 : 11 : : 13 : 20·43 = water and ammonia combined with 11 of anhydrous bisulphate of soda to constitute microcosmic salt. The ammonia amounts to 2·125, which, added to 11, make 13·125; and 20·43 — 2·125 = 18·305. Thus it appears, that ammonio-phosphate of soda is composed of

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1 atom phosphate of soda	7·5
1 atom phosphate of ammonia	5·625
16 atoms water . .	18
	31·125

13. Ammonio-phosphate of magnesia. This salt occasionally crystallizes in stale urine. In such cases it is transparent and colourless, and composed of four-sided rectangular prisms with bases which I believe to be squares. It is formed, likewise, when a soluble phosphate and an ammoniacal salt are added to sulphate of magnesia. It precipitates in the state of a white powder; it is tasteless and insoluble in water. When this powder is dried in the open air I find it composed of

Ammonio-phosphate of magnesia.

1 atom phosphate of magnesia	6
1 atom phosphate of ammonia	5·625
4 atoms water . .	4·5
	16·125

The water exceeds 4 atoms by a quantity which varies from $\frac{1}{4}$ to $\frac{1}{2}$ atom. This excess is doubtless hygrometrical water.

It would appear, from a set of experiments by M. Riffault, that another salt composed of the same acid and bases is occasionally obtained, containing only half the phosphoric acid in the preceding salt. He states the composition of the salt which he analyzed as follows:

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1 atom diphosphate of magnesia	8·5
1 atom diphosphate of ammonia	7·75
5 atoms water . .	5·625
	11·875*

Though I have prepared this compound salt many times, and analyzed it repeatedly, I have never met with any salt composed in the same manner as that examined by Riffault.

Ammonio-arseniate of soda.

14. Ammonio-arseniate of soda. This salt was obtained by M. Mitcherlich, by mixing solutions of arseniate of ammonia and arseniate of soda together. By evaporation the salt crystallizes. The primary form of the crystals is an oblique prism with rhombic bases; the inclination of the faces of the prism is 38° 44′. And, Mitcherlich says, that the ammonio-phosphate of soda crystallizes under the same form.

From the experiments of Mitcherlich, it is evident that the constituents of this salt are

1 atom arseniate of soda	11·750
1 atom arseniate of ammonia	9·875
8 atoms water . .	9·000
	30·625†

Ammonio-permuriate of iron.

15. Ammonio-permuriate of iron. This salt is obtained by mixing permuriate of iron and sal-ammoniac in the atomic proportions, and con-

* Ann. de Chim. et de Phys. XIX. 90. † Ibid. 400.

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centrating the mixture by evaporation. Beautiful octahedrons of a ruby red colour separate by crystallization. This salt is permanent, soluble in water, and its constituents are

1 atom persesquimuriate of iron	11·9375
1 atom sal-ammoniac . .	6·75
	18·6875

It is remarkable that this salt contains no water, though the permuriate of iron has such a tendency to combine with that liquid that it deliquesces when exposed to the air. Indeed, the compound salt itself gradually attracts moisture from the atmosphere.

16. Ammonio-muriate of copper. This salt crystallizes in rectangular prisms terminated by four-sided pyramids. It has a fine green colour, and is composed of

Ammonio-muriate of copper.

2 atoms muriate of copper	19·25
1 atom sal-ammoniac .	6·75
9 atoms water	10·125
	36·125

17. Ammonio-muriate of platinum. This fine yellow salt is anhydrous, and consists of

Ammonio-muriate of platinum.

1 atom bichloride of platinum	21
1 atom sal-ammoniac . .	6·75
	27·75

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Ammonio-oxalate of copper.

18. Ammonio-oxalate of copper. This salt may be obtained by mixing together oxalates of copper and ammonia in the atomic proportions, and digesting the mixture. By evaporation the salt is obtained in rhomboidal plates; it has a blue colour, and is insoluble in water. Vogel of Bareuth first formed it. Water decomposes it. When suddenly heated it detonates loudly, according to Vogel; but this did not take place in my laboratory. Its constituents are

1 atom oxalate of copper	9·5
1 atom oxalate of ammonia	6·625
3 atoms water . .	3·375
	19·5

19. Effloresing ammonio-oxalate of copper. This salt was formed by Vogel of Bareuth, by agitating oxalate of copper in caustic ammonia till a saturated solution was obtained. When this solution is placed in a flat dish it deposites dark blue crystals, having the form of six-sided prisms, with two broad and two narrow faces. When exposed to the air it loses 18 per cent. of its weight; this loss is partly water partly ammonia. The constituents of this salt are as follows:

1 atom oxalic acid .	4·5
1 atom oxide of copper	5
1 atom ammonia .	2·125
1 atom water . .	1·125
	12·75

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From the colour of this salt one would be tempted to consider it as a compound of

1 atom oxalate of ammonia	6·625
1 atom hydrate of copper	6·125
	12·75

But the escape of the ammonia, when the salt is exposed to the air, will not admit of that explanation. It is probably a triple compound of the acid with the two bases at once.

20. Pulverulent ammonio-oxalate of copper. This is a blue powder like *smalt*, formed by Vogel of Bareuth, by putting a greater quantity of oxalate of copper into ammonia than that liquid is capable of dissolving. This salt is anhydrous, and its constituents, according to Vogel's analysis, are as follows:

1 atom oxalate of ammonia	6·625
1 atom dioxalate of copper	14·5
	21·125

II. OF COMPOUND SALTS CONTAINING POTASH.

1. Potash-sulphate of magnesia. This salt crystallizes in transparent rhombs. The taste is weak but sensibly bitter; its specific gravity is 2·112; it is not altered by exposure to the atmosphere. Its constituents are Potash-sulphate of magnesia.

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1 atom sulphate of potash	11
1 atom sulphate of magnesia	7·5
7 atoms water . .	7·875
	26·375

It is, therefore, a compound of 1 integrant particle of sulphate of potash with 1 integrant particle of sulphate of magnesia, retaining all its water of crystallization.

Potash-sulphate of alumina.

2. Potash-sulphate of alumina, or *common alum*. The constituents of this well known salt are

3 atoms sulphate of alumina	21·75
1 atom sulphate of potash	11
25 atoms water . .	28·125
	60·875

Potash-trisulphate of alumina.

3. Potash-trisulphate of alumina. This salt, formerly called *alum saturated with its earth*, may be obtained by adding potash to a boiling solution of alum, and washing the precipitate till the liquid used ceases to act on muriate of barytes. According to Riffault this salt is a compound of

3 atoms trisulphate of alumina	35·25
1 atom sulphate of potash	11·00
9 atoms water .	10·125
	56·375 *

* Ann. de Chim. et de Phys. XVI. 355.

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4. Potash-protosulphate of iron. This salt was obtained by mixing solutions of protosulphate of iron, and sulphate of potash in the atomic proportions, and concentrating the solution—beautiful crystals of the compound salt were deposited. They had a very light green colour, and were much harder and firmer than the protosulphate of iron,—were more opaque, and not liable to undergo any alteration from exposure to the air. The crystals were so irregular that it was difficult to make out the shape; at first view they had a lenticular appearance, but when closely examined, faces appeared which corresponded with those of an octahedron, apparently low, and somewhat broader on two sides than on the other two. The taste of this salt was similar to that of protosulphate of iron; but it was less soluble in water, and the solution, which was almost colourless, had a tendency especially when heated to deposite flocks of peroxide of iron. This salt was analyzed in the following way: Potash-protosulphate of iron.

26·125 grains of the crystals were exposed on a glass capsule to the heat of a spirit lamp, cautiously applied till they ceased to give out moisture. By this treatment they became opaque, and of a dull white colour, and the loss of weight was 5·878 grains. The residual salt was dissolved in water, and the liquid mixed with a solution of 26·5 grains of chloride of barium.

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After the sulphate of barytes had subsided, the residual liquid was neither affected by sulphate of soda nor muriate of barytes. Consequently, 26·125 grains of the salt contain 10 grains of sulphuric acid. Hence, the constituents of the salt are

1 atom protosulphate of iron	9·5
1 atom sulphate of potash .	11
5 atoms water . . .	5·625
	26·125

Potash-persesquisulphate of iron.

5. Potash-persesquisulphate of iron. This salt may be obtained by mixing together solutions of persulphate of iron and sulphate of potash in the requisite proportions, and crystallizing under the vacuum of the air pump along with sulphuric acid to absorb the vapour. The crystals are transparent and colourless, and have the regular octahedral form like alum. The taste is astringent, sour, and sweetish, similar to that of alum, but harsher. The salt dissolves in water, and the liquid containing it has a brownish red colour. I have never succeeded in getting crystals after once dissolving this salt in water. The crystals redden vegetable blues, and are not altered by exposure to the air.

I found by a process quite similar to what has been so often stated, that 64·125 grains of these crystals were just decomposed by 53 grains (13·25 × 4) of chloride of barium, and conse-

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quently, contain just 20 grains of sulphuric acid. I precipitated a solution of 64·125 grains of the salt by ammonia, and the peroxide of iron separated, after being washed, dried, and exposed to a red heat, weighed almost exactly 10 grains. The residual liquid being evaporated to dryness, and the salt remaining exposed to a red heat, left 11¼ grains of sulphate of potash; but it was not quite free from iron. I conclude from this analysis, (which was only once performed) that the constituents of the salt are

2 atoms persesquisulphate of iron	25
1 atom sulphate of potash .	11
25 atoms water . . .	28·125
	64·125

This is the fourth compound salt which we have met with having the regular octahedral form of alum; and all of them contain just 25 atoms of water.

6. Potash-persulphate of iron. During the crystallization of the last described salt, I frequently got, in the first place, a deposition at the bottom of the vessel consisting of a greenish brown matter, obviously crystalline, though the shape was not sufficiently regular to admit of measurement. When this crust was dried in the open air, it had a fine greenish yellow colour, and was composed of grains seemingly cubical, often having the solid angles rounded off, so as

Potash-persulphate of iron.

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to approach to a spherical form. The taste was astringent, sweetish, and acid. The salt reddened vegetable blues, and underwent no sensible alteration from exposure to the air. It dissolved in water, with the exception of a very small flocky sediment too insignificant to be weighed, and doubtless consisting of some accidental impurity. The solution had a yellow colour, and was never transparent even though passed through the filter.

I found that 23·25 grains of this salt were just decomposed by 26·5 grains of chloride of barium, showing that it contained just 10 grains of sulphuric acid. From the same weight of the salt I got very nearly 5 grains of peroxide of iron, and 11 grains of sulphate of potash. Hence, the constituents are

1 atom persulphate of iron	10
1 atom sulphate of potash	11
2 atoms water . .	2·25
	23·25

This is the only persalt of iron which I have examined, in which an atom of the peroxide is combined with an atom of iron.

Potash-sulphate of nickel.

7. Potash-sulphate of nickel. This salt crystallizes in rhomboids having a fine emerald colour. Its taste is sweet, with an impression of bitterness, and it is not altered by exposure to

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the air. Its specific gravity is 2·264. Its constituents, from the analysis of Proust, seem to be

1 atom sulphate of potash	11
1 atom sulphate of nickel	9·25
6 atoms water . .	6·75
	27

8. Potash-sulphate of manganese. This salt crystallizes in thin rhombic plates, having a fine flesh colour. It is not altered by exposure to the air. Its constituents are

Potash-sulphate of manganese.

1 atom sulphate of potash	11
1 atom sulphate of manganese	9·5
5 atoms water	5·625
	26·125

It is therefore a combination of the two salts with the water of crystallization contained in the latter.

9. Potash-sulphate of zinc. This salt crystallizes in long flat rhomboids with angles of 75° and 105°. Its taste is similar to that of sulphate of zinc; it is not altered by exposure to the air. Its constituents are

Potash-sulphate of zinc.

1 atom sulphate of potash	11
1 atom sulphate of zinc	10·25
7 atoms water . . .	7·875
	29·125

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Potash-sulphate of copper.

10. Potash-sulphate of copper. This salt crystallizes in blue coloured rhomboids, with angles of 82° 30′, and 97° 30′. It suffers no change by exposure to the air: its specific gravity is 2·116. According to the analysis of Vogel of Bareuth, which was confirmed in my laboratory, its constituents are

1 atom sulphate of potash	11
1 atom sulphate of copper	10
6 atoms water . . .	6·75
	27·75

Potash carbonate of magnesia.

11. Potash-carbonate of magnesia. When a solution of bicarbonate of potash is poured into a solution of muriate of magnesia, both in the atomic proportions, no precipitate appears at first, but in about twenty-four hours there is a deposite of irregular crystals in groups, which constitute a compound salt. When put into the mouth it appears at first tasteless, but speedily gives an alkaline impression; when cold water is poured on it, the crystals gradually fall to powder, bicarbonate of potash is dissolved, and carbonate of magnesia remains undissolved. When heat is applied to this salt, it gives out water and becomes opaque. If the heat be still farther elevated, carbonic acid gas is driven off, and at a red heat a semifusion takes place. This salt, which is apt to form in chemical analyses of magnesian minerals, has been very carefully

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analyzed by Berzelius, who obtained the following constituents:

Potash	18·233
Magnesia	15·990
Carbonic acid	34·537
Water	31·240
	100·000 *

This salt is undoubtedly a compound of

1 atom bicarbonate of potash	11·5
2 atoms carbonate of magnesia	10·5
9 atoms water	10·125
	32·125

For if we calculate the constituents per cent. of such a compound salt, we obtain

Potash	18·677
Magnesia	15·564
Carbonic acid	34·241
Water	31·518
	100·000

Numbers which are sufficiently near those of Berzelius, to satisfy us that the constituents have been rightly appreciated.

12. Potash-phosphate of soda. This salt was

Potash-phosphate of soda.

* Afhandlingar, VI. 11. There is a translation of the paper of Berzelius in the 1st vol. of the Edinburgh Philosophical Journal, p. 63; but the translation is often erroneous, obviously from the translator's ignorance of the subject.

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formed by M. Mitcherlich, by saturating the biphosphate of potash with carbonate of soda, and crystallizing the solution. The primary form of the crystal is an oblique prism with a rhombic base. The inclination of the faces of the prism is, according to Mitcherlich's measurement, 78° 40′. The constituents of the salt from Mitcherlich's experiments, seem to be the following:

1 atom phosphate of potash	9·5
1 atom phosphate of soda	7·5
15 atoms water	16·875
	33·875

The quantity of water found by Mitcherlich, somewhat exceeded 15 atoms: for it was 17·272, which exceeds 15 atoms by about one-third of an atom.

Potash-arseniate of soda.

13. Potash-arseniate of soda. This salt was formed by Mitcherlich in the same way as the preceding; the form of its crystals is the same also. Its constituents, according to Mitcherlich's analysis, are as follows:

1 atom arseniate of potash	13·75
1 atom arseniate of soda	11·75
18 atoms water	20·25
	45·75 *

Potash oxalate of copper.

14. Potash-oxalate of copper. This salt was

* Ann. de Chim. et de Phys. XIX. 396.

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first formed by Vogel of Bareuth, by digesting together binoxalate of potash and carbonate of copper. When the solution is concentrated, two species of salts are obtained.

The first species crystallizes in long slender six-sided prisms, which effloresce in the air. They are composed of

1 atom oxalate of potash	10·5
1 atom oxalate of copper	9·5
4 atoms water	4·5
	24·5

The second species forms oblique four-sided prisms with rhombic bases. It has a greener colour than the first species, and is not altered by exposure to the air. Its constituents are

1 atom oxalate of potash	10·5
1 atom oxalate of copper	9·5
2 atoms water	2·25
	22·25

15. Potash-tartrate of soda. This is the well known salt formed by saturating bitartrate of potash with carbonate of soda and crystallizing the solution. It forms large crystals, which seem to have for a primary form, a right prism with a rectangular base; it has a bitter taste, is very soluble in water, and effloresces slightly, when exposed to the air. Its constituents are

Potash-tartrate of soda.

1 atom tartrate of potash	14·25
1 atom tartrate of soda	12·25
8 atoms water	9·00
	35·5

Here the water of crystallization is twice as great as in the two salts uncombined: for the two salts contain each 2 atoms of water.*

Tartar emetic.

16. Tartar emetic. This well known salt is formed by boiling together cream of tartar and glass of antimony in fine powder. The filtered solution, when sufficiently concentrated, deposites white coloured crystals of tartar emetic; the crystals are usually tetrahedrons; it is commonly opaque, and very irregular in its shape; it requires about 14½ times its weight of cold water to dissolve it, but it is much more soluble in hot water. No accurate analysis of this useful salt having been hitherto made, I took the following method of ascertaining its constituents:

* I have analyzed crystals of this salt after standing for a fortnight on blotting paper in my laboratory, and found them composed of

1 atom tartrate of potash	14·25
1 atom tartrate of soda	12·25
10 atoms water . .	11·25
	37·75

But I ascribed this difference to the difficulty of getting rid of the hygrometrical moisture. The crystals containing 8 atoms water, were large and firm, and consequently, much freer from adhering moisture than the small crystals formed in my laboratory.

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50 grains of picked crystals of tartar emetic were dissolved in distilled water, and a current of sulphuretted hydrogen gas passed through the liquid as long as any precipitate fell. The hydro-sulphuret of antimony thus obtained, when dried in the open air, weighed 42·21 grains; but when heated in a glass tube, water was driven off, and a black matter remained, which weighed 24·59 grains, and which was sulphuret of antimony, equivalent to 18·032 grains of antimony, or 21·31 grains of protoxide of antimony.

The liquid thus freed from antimony, was evaporated cautiously, and a quantity of bitartrate of potash obtained, which weighed 28·69 grains. But the integrant particle of bitartrate of potash weighs 24·75; and 28·60 : 24·75 : : 21·31 : 18·384 = the protoxide of antimony united to an integrant particle of bitartrate of potash. Now, the protoxide of antimony weighs 6·5, and 6·5 × 3 = 19·5; this is a little more than I actually found, because part of the sulphuret in my experiment adhered to the glass tube, and could not be collected without loss. From this experiment, which I thrice repeated, I have no doubt that the constituents of tartar emetic are

2 atoms tartaric acid .	16·5
3 atoms protoxide of antimony	19·5
1 atom potash . .	6·0
2 atoms water .	2·25
	44·25

This must be acknowledged a very curious combination. It might be called a *ditartrate of potash and antimony;* for 1 atom of tartaric acid must be combined with 2 atoms of protoxide of antimony, while the other atom of acid is divided between the atom of potash and the remaining atoms of protoxide of antimony.

Sulpho-chromate of potash.

17. Sulpho-chromate of potash. This salt was obtained by mixing together solutions of chromate of potash and sulphate of potash, in the proportion of 3 atoms of the former to 1 atom of the latter. On concentrating the mixture and setting it aside, the first crystals which were deposited had a greenish yellow colour, and were either in octahedrons or four-sided rectangular prisms terminated by four-sided pyramids. These last were obviously the regular octahedron with a prism interposed between its pyramids. The crystals were small, but very regular and transparent; the taste was saline and bitter; and the salt was not very soluble in water. When this salt was heated to redness it became opaque, but did not lose any weight,—it was therefore anhydrous. After some unsuccessful attempts to analyze this salt by means of tartaric acid it was treated in the following way:

78·5 grains of it were dissolved in water, and precipitated by a neutral solution of protonitrate of mercury. The precipitate being edulcorated,

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and dried, weighed almost exactly 32·5 grains, equivalent to 6·5 grains of chromic acid.

The liquid thus freed from chromic acid was evaporated to dryness, and heated to redness in a platinum vessel to get rid of any excess of mercury that might have been added. It was then dissolved in water, and the sulphuric acid precipitated by muriate of barytes. The precipitate, after being washed, dried, and heated to redness, weighed 88·55 grains, containing 30 grains of sulphuric acid. But 30 grains of this acid is equivalent to 6 atoms, requiring for saturation 6 atoms or 36 grains of potash ; while the 6·5 grains of chromic acid require for saturation 6 grains of potash. It is obvious, from this analysis, that the constituents of this compound salt are

6 atoms sulphate of potash	66
1 atom chromate of potash	12·5
	78·5

III. OF COMPOUND SALTS CONTAINING NEITHER POTASH NOR AMMONIA.

1. Carbo-tartrate of alumina-and-soda. When solutions of tartrate of alumina and carbonate of soda, each in the atomic proportions, are mixed together, no precipitate falls ; but when the mix- Carbo-tartrate of alumina-and-soda.

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ture is left to spontaneous evaporation a transparent colourless salt gradually appears, crystallized in long prisms, apparently four-sided but rather indistinct. These crystals do not affect litmus or cudbear paper; they have a disagreeable taste bearing a certain resemblance to that of sulphate of zinc. As the whole of the liquid shoots into these crystals, it is evident, that the compound salt consists of an integrant particle of tartrate of alumina and an integrant particle of carbonate of soda united together. From the weight of the compound salt, compared with that of the two constituents, it was easy to infer that it contained 9 atoms water. Hence, the constituents of the salt are

1 atom tartrate of alumina	10·5
1 atom carbonate of soda	6·75
9 atoms water . .	10·125
	27·375

Magnesio-carbonate of lime.

2. Magnesio-carbonate of lime. The mineral known by the name of dolomite, when amorphous, and of rhombspar or bitter spar, when in crystals, is too well known to require any particular description. If any confidence can be put in Klaproth's analyses, there are two distinct species of this mineral:

(1.) The common dolomite and magnesian limestone, are composed of

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1 atom carbonate of lime	6·25
1 atom carbonate of magnesia	5·25
	11·5

I find the magnesian limestone of Sunderland is composed of these proportions.

(2.) Rhombspar, on the other hand, as is obvious from the analyses of Klaproth, is a compound of

2 atoms carbonate of lime	12·5
1 atom carbonate of magnesia	5·25
	17·75

3. Boro-tartrate of potash-and-soda.* This is the well known salt which has a place in several of the foreign pharmacopœias under the name of *cremor tartari solubilis.* It is made by dissolving 1 part of borax in 8 parts of boiling water, and adding to the solution as much bitartrate of potash as it will dissolve. The solution is filtered and evaporated to dryness in a gentle heat. The compound salt thus prepared, is employed in dropsy and amenorrhæa, and possesses nearly the same virtues as bitartrate of potash. Its taste is cooling, bitter, and much more disagreeable than that of cream of tartar,

Boro-tartrate of potash-and-soda.

* Though this salt contains potash, I have thought it better to place it here than among the compound salts of potash, for reasons that will be easily perceived by the attentive reader.

without any of the sourness which distinguishes that salt. When exposed to a moderate heat on the sand bath, it gradually becomes solid, without exhibiting any tendency to crystallization or losing any of its transparency. Its colour becomes slightly yellow, and it bears some resemblance to nut oil prepared for printers' ink, and the process continued till the oil becomes solid. When the compound salt is weighed in this state, it is found precisely equal to the weight of the two salts employed to form it. Consequently, each salt retains its water of crystallization. By exposure to the air it slowly deliquesces. The constituents are

1 atom biborate of soda	10
2 atoms bitartrate of potash	22·5
12 atoms water	13·5
	46

Soda sulphate of lime.

4. Soda-sulphate of lime. This is the name which designates the substance known to mineralogists by the name of Glauberite, and found originally embedded in rock salt, about ten leagues south of Madrid, at Vela Rubia, and more lately, in the blue salt of Ischel in Upper Austria. It is crystallized in oblique rhombic prisms, and is composed of

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1 atom sulphate of lime	8·5
1 atom sulphate of soda	9
	17·5

As is evident from the analysis of Brogniart.

5. Soda-sulphate of alumina, or soda-alum. Soda alum. This species of alum has been hitherto overlooked by chemists, in consequence of its great solubility, and the consequent difficulty of obtaining it in regular crystals. I have been informed by my friend, Charles Macintosh, Esq. of Glasgow, that he made it more than twenty years ago. For the specimen which I examined, I am indebted to Mr. John Wilson of Hurlet, who first drew my attention to it, and furnished me with very pure specimens. The salt was noticed in 1810, by Mr. Winter, in his account of the Whitby alum processes.* In appearance, *soda-alum* cannot be distinguished from common alum; the crystals are regular octahedrons, or forms obviously derived from the common octahedron: the taste is the same as that of common alum. It undergoes no alteration from exposure to the air, if pure, but it is frequently impure, and in that case effloresces on the surface. The great solubility of this alum is its great characteristic property. It is more than thirty times more soluble in cold water than ammoniacal alum, and more than twenty times

* Nicholson's Jour. XXV. 254, 255.

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more soluble than potash alum. For I find that at the temperatue of 60°, 100 parts of water dissolve

9·37 parts of ammoniacal alum
14·79 parts of potash alum
327·6 parts of soda alum.

This great solubility would make soda-alum more convenient for the use of dyers and printers than common alum, if it could be procured with the same facility. When soda-alum is heated on the sand bath, it undergoes very nearly the same loss of weight as common alum. For 100 parts in my trials lost 44·1 parts of water of crystallization.

I found by experiment that 58·875 grains of the crystals of this alum are just decomposed by 53 grains (13·25 × 4) of chloride of barium, and consequently, contain exactly 20 grains of sulphuric acid. From 58·875 grains of the same crystals, I got almost exactly 6·75 grains of alumina and 9·5 grains of anhydrous sulphate of soda; the excess, amounting to 0·5 grain, was owing to sulphate of lime obviously derived from the filter. From this analysis it follows that the constituents of soda-alum are

3 atoms sulphate of alumina	21·75
1 atom sulphate of soda	9
25 atoms water	28·125
	58·875

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Thus, there are no fewer than five species of compound salts, having each the form of the regular octahedron, and containing each the same number of atoms of water. These are

1. Ammoniacal alum,
2. Potash alum,
3. Soda alum,
4. Ammonio-persesquisulphate of iron,
5. Potash-persesquisulphate of iron.

Were we to confine our views to the first three species, we would be tempted to conclude with M. Mitcherlich, that sulphate of ammonia, sulphate of potash, and sulphate of soda are isomorphous salts; while in the fourth and fifth species the alumina is replaced by peroxide of iron. And Mitcherlich has shown that alumina and peroxide of iron are isomorphous substances.

In consequence of this last circumstance, it is obvious that alum is very likely to contain peroxide of iron, unless very great care indeed be taken in preparing it. The only certain way of obtaining it quite free from iron would be to dissolve clay free from iron in sulphuric acid, and to crystallize the solution by adding the requisite quantity of sulphate of ammonia and sulphate of potash. I am satisfied that at the present price of sulphuric acid, such a manufactory might be established with advantage.

Calcareo-acetate of copper.

6. Calcareo-acetate of copper. This is an exceedingly beautiful salt of a fine deep blue co-

lour, and crystallized in six-sided prisms, which Mr. Ramsay of Glasgow prepares for the use of the calico printers. It is pretty soluble in water, and has the peculiar disagreeable taste which distinguishes the cupreous salts. It seems to have been crystallized from a liquid containing an excess of acetate of lime: for when the crystals are kept for some time, they become spotted on the surface with small white crusts, which I find to consist of acetate of lime. The result of a careful analysis of this salt in my laboratory gives the constituents as follows:

1 atom acetate of lime	9·75
1 atom acetate of copper	11·25
6 atoms water	6·75
	27·75

Soda-oxalate of copper.

7. Soda-oxalate of copper. M. Vogel of Bareuth prepared this salt by saturating bin-oxalate of potash with soda, and pouring a saturated solution of sulphate of copper into the liquid. A pulverulent precipitate fell, which was redissolved by agitation; the liquid being concentrated, the potash-oxalate of copper first crystallized; afterwards, crystals of soda-oxalate of copper were deposited. They were feather shaped, and consisted of four-sided prisms sometimes flattened. This salt is insoluble in water. At first it has a sky blue colour, but by exposure to

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the light it becomes first green, and afterwards brown, without any other apparent alteration. I have not myself made any experiments on this salt; but from the analysis of it by Mr. Vogel, there can be no doubt that it is composed of

1 atom oxalate of soda	8·5
1 atom oxalate of copper	9·5
2 atoms water	2·25
	20·25

Carbono-phosphate of soda.

8. Carbono-phosphate of soda. There is a prussian blue manufactory in the neighbourhood of Glasgow belonging to Mr. Macintosh, in which, likewise, prussiate of potash is made in very considerable quantities. The acid is obtained by the combustion of the hoofs of black cattle, imported chiefly from Ireland; and the hoofs of a thousand cattle are required for every day's consumption in the manufactory. The slaughtering of cattle in Ireland having considerably diminished at the end of the last war, hoofs became scarce. This induced Mr. Macintosh to substitute the animal substance called cracknales, procured chiefly, I believe, from the candle makers. Soon after this substitution, considerable quantities of a white salt in fine needles began to make their appearance in the prussiate of potash leys, and incommoded the process considerably. These crystals exhibiting appearances different from any of the common

salts, Mr. Macintosh sent me a quantity of them to ascertain their nature.

The crystals were pretty regular six-sided prisms, which were obtained of a pretty large size by a second crystallization. The taste was cooling, and alkaline, and they rendered cudbear paper violet, indicating the presence of an alkali. The salt was pretty soluble in water, and the crystals were not altered by exposure to the air. They effervesced slightly, but distinctly in nitric acid.

I neutralized a portion of these crystals by means of nitric acid, and then mixed the solution with a sufficient quantity of nitrate of barytes—a white precipitate fell, which, when washed, and dried on the filter, was a beautiful white soft powder, which dissolved without effervescence in nitric acid, was again precipitated by ammonia, and exhibited all the properties of phosphate of barytes. I therefore decomposed a portion of it by means of sulphuric acid. The acid which I obtained possessed the following properties:

It threw down nitrate of barytes, and nitrate of lead white, and both precipitates were dissolved by nitric acid. Persulphate of iron was thrown down white, and the precipitate became red when digested in potash ley. Nitrate of silver was thrown down yellow, and the precipitate was dissolved in nitric acid. Muriate of

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lime, muriate of magnesia, nitrate of strontian, sulphate of copper, sulphate of zinc, nitrate of mercury, were not precipitated. From these properties, there could be no doubt that the acid in the salt was chiefly the phosphoric.—I now dissolved a quantity of the salt in water, and neutralized it exactly with sulphuric acid; the solution was then concentrated, and set aside. It shot out into crystals of sulphate of soda, and phosphate of soda, easily recognized by their shape.

To ascertain the proportions of the constituents, I dissolved 200 grains of the crystals in water, neutralized the solution with nitric acid, and precipitated by nitrate of lead. The precipitate weighed 141·3 grains, equivalent to 28·26 grains of phosphoric acid. The residual liquid contained no lead, but was entirely nitrate of soda, weighing 109·5 grains, equivalent to 40·74 grains of soda. Now, 28·26 grains of phosphoric acid require for saturation 32·297 grains of soda. There remain 7·443 grains of soda, which require for saturation 5·117 grains of carbonic acid.

Thus, the constituents of the salt are

Phosphoric acid	28·260	or	14
Carbonic acid	5·117	-	2·535
Soda . .	40·740	-	20·182
Water . .	125·883	-	62·36
	200·000		

Now,

4 atoms phosphoric acid	= 14
1 atom carbonic acid	= 2·75
5 atoms soda . .	= 20
55 atoms water .	= 61·875

Hence, I am disposed to consider the salt as a compound of

4 atoms phosphate of soda	30
1 atom carbonate of soda	6·75
55 atoms water . .	61·875
	98·625

If this be really a compound of phosphate and carbonate of soda, the union is very slight; for I found that by repeated solutions, and crystallizations, I could separate from it phosphate of soda in the usual rhomboidal form. What leads to the notion that it is a compound salt, is the form of the crystals—a six-sided prism apparently regular, which could not be derived from the primary form of phosphate of soda. Nor is the water of crystallization what it would be if the salt were a mere mixture of 4 atoms of phosphate of soda, and 1 atom of carbonate of soda; for phosphate of soda containing 12 atoms, and carbonate of soda 10 atoms, the water of crystallization should have amounted to 58 atoms, instead of 55—the quantity found, unless there was an error in the analysis. I do not well see,

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however, how any supposed error could serve to diminish the apparent quantity of water in the salt; but it is possible that the salt may have sustained a loss of water before I began to examine it.

CHAP. XIX.

SOME GENERAL OBSERVATIONS ON THE ATOMIC WEIGHTS OF CHEMICAL BODIES.

1. Hydrogen is the lightest of all known bodies. Its atomic weight is 0·125.

2. The atomic weights of all the other simple bodies are multiples of 0·25 = 2 atoms of hydrogen. Consequently, the number denoting the atomic weight of each is either a whole number, or a mixed number, ending with one or other of these decimals:—0·25, 0·5, 0·75.

3. The atomic weights of the supporters are as follows:

Oxygen	1
Chlorine	4·5
Iodine	15·5

They are all multiples of 0·5, or of 4 atoms of hydrogen.

4. The atomic weights of the acidifiable combustibles are as follows (omitting hydrogen): Acidifiable combustibles.

1. Carbon	0·75	6. Sulphur	2
2. Boron	1	7. Tellurium	4
3. Silicon	1	8. Arsenic	4·75
4. Phosphorus	1·5	9. Selenium	5
5. Azote	1·75		

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They are all whole numbers, or terminate in 0·5 or 0·75—they never terminate in 0·25.

5 are multiples of 8 atoms of hydrogen.
1 is a multiple of 4 — —
3 are multiples of 2 — —

Intermediate combustibles.

5. The atomic weights of the intermediate combustibles are as follows:

1. Chromium	.	3·5	5. Tungsten	.	15·75
2. Titanium	.	4	6. Columbium	.	18
3. Antimony	.	5·5	7. Uranium	.	26
4. Molybdenum	.	6			

These, like the former set, are either whole numbers, or they end in 0·5 or 0·75, and never in 0·25.

4 are multiples of 8 atoms hydrogen.
2 are multiples of 4 — —
1 is a multiple of 2 — —

Alkalifiable combustibles.

6. The atomic weights of the alkalifiable combustibles are as follows:

1. Lithium	.	1·25	10. Manganese	.	3·5
2. Aluminum	.	1·25	11. Iridium	.	3·75
3. Magnesium	.	1·5	12. Copper	.	4
4. Glucinum	.	2·25	13. Yttrium	.	4·25
5. Calcium	.	2·5	14. Zinc	.	4·25
6. Sodium	.	3	15. Potassium	.	5
7. Nickel	.	3·25	16. Zirconium	.	5
8. Cobalt	.	3·25	17. Strontium	.	5·5
9. Iron	.	3·5	18. Rhodium	.	5·5

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19.	Cerium	6·25	25.	Platinum	12
20.	Cadmium	7	26.	Lead	13
21.	Palladium	7	27.	Silver	13·75
22.	Tin	7·25	28.	Mercury	25
23.	Barium	8·75	29.	Gold	25
24.	Bismuth	9			

They are either whole numbers, or they terminate in 0·25 or 0·5 ; and very rarely in 0·75.

11 are multiples of 8 atoms of hydrogen,
6 are multiples of 4 — —
12 are multiples of 2 — —

Only 3 of them end in 0·75 ; namely, iridium, barium, and silver.

7. The simple combustibles (excluding hydrogen) amount to 44. Of these

20 (or almost the half) are multiples of oxygen, and consequently whole numbers.
9 are multiples of 4 atoms of hydrogen, and consequently terminate in 0·5.
9 terminate in 0·25, being multiples of 2 atoms of hydrogen.
6 terminate in 0·75, being likewise multiples of 2 atoms hydrogen.

8. When an acidifiable combustible terminates in 0·75, the acid, which it forms, does not act with much energy; but when an alkalifiable combustible terminates in 0·75 the base formed is usually energetic. How far this applies to iridium is uncertain ; but it applies well both to barytes and oxide of silver.

Acids. 9. The acids are all compound bodies. They may, with reference to their atomic weights, be divided into three classes: 1. Combinations of a simple acidifiable or intermediate combustible with oxygen. 2. Acids, consisting of oxygen united to two bases at once, or undecomposed acids. 3. Hydracids, consisting of a simple or compound supporter united to an atom of hydrogen. The following table exhibits the atomic weights of all these acids:

1. OXYGEN UNITED TO A SINGLE BASE.

1. Silicic	2	14. Chromic	6·5
2. Phosphorous	2·5	15. Arsenious	6·75
3. Carbonic	2·75	16. Nitric	6·75
4. Boracic	3	17. Selenic	7
5. Hyposulphurous	3	18. Antimonic	7·5
6. Phosphoric	3·5	19. Manganesic	7·5
7. Sulphurous	4	20. Arsenic	7·75
8. Oxalic	4·5	21. Molybdous	8
9. Hyponitrous acid	4·75	22. Hyposulphuric	9
10. Sulphuric	5	23. Molybdic	9
11. Oxide of tellurium	5	24. Tungstic	18·75
12. Nitrous acid	5·75	25. Columbic	19
13. Titanic	6	26. Uranitic	28

2. OXYGEN UNITED TO A DOUBLE BASE—AND UNDECOMPOSED ACID.

1. Fluoric	1·25	6. Citric	7·25
2. Fluosilicic	3·25	7. Tartaric	8·25
3. Fluoboric	4·25	8. Uric	9
4. Acetic	6·25	9. Saclactic	13
5. Succinic	6·25	10. Benzoic	15

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3. HYDRACIDS.

1. Hydrocianic .	3·375	3. Muriatic .	4·625
2. Formic .	4·625	5. Hydriodic .	15·625

Of the first set 12 are whole numbers; 6 end in 0·5 and 4 in 0·75. Or, in other words,

12 are multiples of oxygen,
6 are multiples of 4 atoms of hydrogen,
4 are multiples of 2 atoms of hydrogen.

Of the second set 3 are whole numbers, and the other 7 end in 0·25. Or, in other words,

3 are multiples of 1 atom of oxygen,
7 are multiples of 2 atoms of hydrogen.

The third set containing an atom of hydrogen united to an atom of a simple or compound supporter or acid, it is obvious that they can only be multiples of 1 atom of hydrogen. Accordingly, they end either in 0·625 or in 0·375.

10. The atomic weights of the bases (excluding ammonia) are as follows: Bases.

1. Lithia .	2·25	10. Protoxide of manganese .	4·5
2. Alumina .	2·25	11. Protoxide of chromium .	4·5
3. Magnesia .	2·5	12. Peroxide of iron	5
4. Glucina .	3·25	13. Deutoxide of manganese .	5
5. Lime .	3·5	14. Oxide of copper	5
6. Soda .	4	15. Yttria .	5·25
7. Protoxide of nickel	4·25		
8. Protoxide of cobalt	4·25		
9. Protoxide of iron	4·5		

16.	Oxide of zinc	5·25	
17.	Potash	6	
18.	Zirconia	6	
19.	Strontian	6·5	
20.	Protoxide of antimony	6·5	
21.	Protoxide of cerium	7·25	
22.	Deutoxide of rhodium	7·5	
23.	Peroxide of cerium	7·75	
24.	Oxide of palladium	8	
25.	Protoxide of tin	8·25	
26.	Peroxide of tin	9·25	
27.	Barytes	9·75	
28.	Oxide of bismuth	10	
29.	Peroxide of platinum	14	
30.	Protoxide of lead	14	
31.	Oxide of silver	14·75	
32.	Protoxide of ♆	26	
33.	Peroxide of ♆	27	
34.	Protoxide of uranium	27	
35.	Peroxide of uranium	28	

14 of these are whole numbers; 8 end in 0·5, 10 in 0·25, and 3 in 0·75. Or, in other words,

14 are multiples of an atom of oxygen,
8 are multiples of 4 atoms of hydrogen,
13 are multiples of 2 atoms of hydrogen.

Ammonia being a compound of hydrogen, and containing 3 atoms of it, is obviously only a multiple of 1 atom of hydrogen.

11. Thus it appears, that out of 117 bodies, the atomic weights of which have been accurately determined in this work, there are only 5 which are merely multiples of 1 atom of hydrogen,—these are the four hydracids and ammonia. The four acids contain each 1 atom of hydrogen, and ammonia contains 3 atoms of hydrogen. 37 are multiples of 2 atoms of hydrogen, 11 of which are acids and 11 bases. The rest simple bodies.

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25 are multiples of 4 atoms of hydrogen. Of these 6 are acids, 8 bases; 2 supporters, 3 acidifiable combustibles, and 6 alkalifiable.

50 are multiples of an atom of oxygen, and consequently whole numbers. Of these 15 are acids, 14 bases, 1 supporter, 9 acidifiable combustibles, and 11 alkalifiable combustibles.

12. It is obvious that all those bodies whose atomic weights are represented by whole numbers are multiples of the atomic weight of oxygen.

18 simple bodies are in this predicament, namely,

Boron,	Columbium,	Cadmium,
Silicon,	Uranium,	Palladium,
Sulphur,	Sodium,	Bismuth,
Tellurium,	Copper,	Platinum,
Selenium,	Potassium,	Lead,
Molybdenum,	Zirconium,	Titanium.

Most of the compounds of these bodies (to the amount of 28) are also whole numbers, and of course multiples of oxygen. This is the case also with three combustible acids; namely, uric, saclactic, and benzoic.

13. There are five or six of the simple bodies which we have found to combine both with 1 atom and with 1½ atom of oxygen. This anomaly, I have no doubt, will startle many of my readers, and may even induce several persons to reject the whole system without farther exami-

Whether 1½ atom of oxygen unite to bodies.

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nation. I have sometimes thought that the anomaly might be obviated by admitting, that oxygen in reality has an atomic weight amounting to 0·5 instead of 1 ;—on that supposition, it will have the property of usually entering into combinations by 2 atoms at a time. All those compounds which I have considered as containing only 1 atom of oxygen, will in reality contain 2 ; and those which I suppose to contain 1½ atom will contain 3 atoms. This supposition, if admitted, will make no alteration in the atomic weights given in this work; it will only alter our way of viewing them, and 1, instead of denoting the weight of 1 atom oxygen will represent 2 atoms. It will be more convenient to retain these atomic weights even if this new view of the subject should be ultimately adopted; because, it is but very seldom that a less quantity of oxygen enters into combination with other bodies than what we have denoted by 1. One, then, may still be considered as the representative of a compound atom of oxygen, because it is the common multiple of it which enters into combinations; though in a few rare instances we find that 0·5, or a simple atom of it, also unites with other bodies. Such combinations constitute the peroxides of iron, nickel, cobalt, cerium, and sodium, and likewise the deutoxide of manganese.

Atom of oxygen may be = 0·5.

If we embrace this view of the subject, which

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in the present state of our knowledge is by far the most probable, then, not only those simple bodies whose atomic weights are whole numbers, but those likewise, whose weights end in 0·5, are multiples of oxygen. These constitute the whole of the supporters of combustion, and all the acidifiable and intermediate combustibles, except three; namely, carbon, arsenic, and tungsten. Of the alkalifiable combustibles, amounting to 29, 17 would be multiples of oxygen, leaving altogether, 15 simple bodies, which are multiples of 2 atoms of hydrogen. Thus 31 simple bodies would be multiples of oxygen, and 15 multiples of 2 atoms of hydrogen.

14. There are only 5 simple bodies which are multiples of 2 atoms of water, or 2·25. These are

Chlorine	4·5	or	4 water.
Tungsten	15·75	-	14 -
Columbium	18	-	16 -
Glucinum	2·25	-	2 -
Bismuth	9	-	8 -

But there are 12 compound bodies in the same predicament: viz.

Oxalic acid .	4·5	or	4 water.
Arsenious acid .	6·75	-	6 -
Hyposulphuric .	9	-	8 -
Molybdic . .	9	-	8 -
Uric acid . .	9	-	8 -

Lithia . .	2·25	or	2 water.
Alumina . .	2·25	-	2 -
Protoxide of iron	4·5	-	4 -
Protoxide of manganese	4·5	-	4 -
Peroxide of mercury	27	-	24 -
Protoxide of uranium	27	-	24 -

These comparisons might be carried a good deal farther. A bare inspection of the tables at the beginning of this chapter will enable the reader to perceive the relations which exist between the atomic weights of different bodies. Thus

The atomic weight of carbon is		0·75
That of phosphorus is	0·75 × 2 =	1·5
sodium	1·5 × 2 =	3
molybdenum	3 × 2 =	6
platinum	6 × 2 =	12

Or, in other words, the atom of

Phosphorus is	= 2 carbon.
Sodium	= 4 -
Molybdenum	= 8 -
Platinum	= 16 -

In like manner, the atom of

Glucinum is	= 3 carbon.
Oxalic acid, Protoxide of iron, Protoxide of manganese	= 6 -
Bismuth	= 12 -

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These, and many other similar relations between the atomic weights of the different bodies, will be obvious by barely inspecting the tables, and need not therefore be pointed out.

Water of crystallization of the salt.

15. Though the seventeenth and eighteenth chapters of this work exhibit the composition of 307 salts, a greater number than has ever before been subjected to actual analysis by any individual, yet they do not enable us to detect any law with respect to the number of atoms of water which exist in the salts in the state of water of crystallization. Of these 307 species of salts, eighty are anhydrous—thirty-one contain 1 atom of water—fifty contain 2 atoms—twenty-seven 3 atoms—eighteen 4 atoms—twelve 5 atoms—nineteen 6 atoms—eighteen 7 atoms—ten 8 atoms—four 9 atoms; all of which are compound salts—six contain 10 atoms—none contain 11 atoms—and two contain 12 atoms.

No simple salt has been met with containing more than 12 atoms, except the sesquinitrate of uranium, which seems to contain 17 atoms. But the compound salts are found with a much greater quantity of water. Thus, one contains 16 atoms of water—five contain 25 atoms—and one contains 55 atoms. Next to the anhydrous salts, by far the most abundant are the salts which contain 2 atoms of water. The salts containing 1, 2, and 3 atoms, added together,

constitute about the half of the whole, if we exclude the anhydrous salts.

If we except acetate of ammonia and quadroxalate of potash, none of the salts of ammonia, potash, soda, barytes, strontian, or lime, contain 7 atoms of water. And, except phosphate of magnesia, all the salts which contain 7 atoms water are either sulphates or nitrates. The metalline sulphates seem to affect 7 atoms water.

No salt of barytes, strontian, iron, manganese, bismuth, or mercury, contains 6 atoms of water; and only 14 simple salts occur containing that quantity of water. The other five are compound salts.

Salts containing 5, 8, 10, and 12 atoms are very rare. No salt has been met with containing 11 atoms.

The oxalates are either anhydrous, or they contain 1, 2, or 3 atoms of water. Only 2 salts contain more: namely, the oxalate of nickel, which contains 4, and the quadroxalate of potash, which contains 7 atoms.

The tartrates are either anhydrous, or they contain 1, 2, or 3 atoms of water. One salt contains 4 atoms, the tartrate of lime, and one contains 5 atoms, the tartrate of bismuth.

The acetates vary much more in their composition. They occur with 1, 2, 3, 4, 6, and 7 atoms water; but very rarely anhydrous.

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16. Before concluding these general observations, I may say a few words respecting Berzelius' law, that "in all salts the atoms of oxygen in the acid constitute a multiple by a whole number of the atoms of oxygen in the base." This law was founded upon the first set of exact analyses of neutral salts which Berzelius made. Now, as neutral salts in general are combinations of an atom of a protoxide with an atom of an acid, it is obvious that the atoms of oxygen in the acid must in all such salts be multiples of the atom of oxygen in the base; because every whole number is a multiple of unity. Neutral salts, therefore, are not the kind of salts by means of which the precision of this supposed law can be put to the test.

Inquiry into the accuracy of Berzelius' empyrical law.

Even in the subsalts, composed of 1 atom of acid united to 2 atoms of base, it is obvious enough, that the law will hold whenever the acid combined with the base happens to contain 2 or 4, or any even number of atoms; because all even numbers are multiples of 2. Now, this is the case with the following acids:

Phosphoric,	Nitrous,	Antimonic,	Citric,
Carbonic,	Titanic,	Manganesic,	Saclactic,
Boracic,	Arsenious,	Molybdous,	Chromous.
Sulphurous,	Selenic,	Uranitic,	

Consequently, the law must hold good in all

combinations of 1 atom of these acids with 2 atoms of base.

In the case of all those acids which contain only 1 atom of oxygen, all the subsalts composed of 1 atom of the acid united to 2 atoms of base, the law will also in some sort hold; for the atoms of the oxygen in such acids being 1, this number will always be a submultiple of 2, the number of atoms of oxygen in 2 atoms of base. This is the case with the following acids:

Silicic,	Hyposulphurous,
Phosphorous,	Oxide of tellurium.

It is only in the subsalts of acids containing an odd number of atoms of oxygen, that exceptions to the law can exist. It is to them, therefore, that we must have recourse when we wish to determine whether this empyrical law of Berzelius be founded in nature or not. Now, there are thirteen acids, the integrant particles of which contain an odd number of atoms of oxygen. The following table exhibits the names of these acids, together with the number of atoms of oxygen in each.

	ATOMS OF OXYGEN.		ATOMS OF OXYGEN.
Sulphuric acid	3	Acetic acid	3
Arsenic	3	Succinic	3
Chromic	3	Benzoic	3
Molybdic	3	Nitric	5
Tungstic	3	Tartaric	5
Oxalic	3	Hyposulphuric	2½
Formic	3		

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Now, although the number of subsalts which I have examined is exceedingly small, because my object was not to investigate the truth of Berzelius' law, but to determine the quantity of water of crystallization which the salts contain, yet there occur several which are inconsistent with Berzelius' law. This is the case, for example, with the disulphate of alumina, the atoms of oxygen in the base being 2, and those in the acid 3. The following subsalts are precisely in the same predicament:

	ATOMS OF OXYGEN IN BASE.	DITTO IN ACID.
Dinitrate of alumina	2	5
Trisnitrate of alumina	3	5
Diprotarseniate of iron	2	3
Dinitrate of lead	2	5
Diacetate of lead	2	3
Diacetate of copper (verdigris)	2	3
Dinitrate of bismuth	2	5

These examples comprehend not only nitric acid, which Berzelius has recognised as an exception to his law; but likewise, sulphuric acid, arsenic acid, and acetic acid.

It would certainly be a most remarkable circumstance if 2 atoms of any protoxide were incapable of combining with 1 atom of any of the 13 acids in the preceding list. I have given seven examples of such combinations; and am persuaded that many more will be discovered

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whenever the attention of chemists is particularly turned to the subsalts.

There is another kind of saline combination in which exceptions to the law of Berzelius may also be looked for; I mean those salts which I have distinguished by the epithet *sesquisalts* or *subsesquisalts*. In the sesquisalts, $1\frac{1}{2}$ atom of acid unite with 1 atom of base; or, which comes to the same thing, 3 atoms of acid unite with 2 atoms of base. In the subsesquisalts, $1\frac{1}{2}$ atom of the base unite with 1 atom of the acid; for example, the *sesquicolumbate* of barytes is composed of

3 atoms columbic acid,	containing	3 atoms oxygen.
2 atoms barytes	———	2 —— ———

Here we see, that the oxygen of the acid is not a multiple of that in the base.

When the acid contains 2 atoms of oxygen, and the base 1 atom, it is plain that the sesquisalts must all come under Berzelius' law; because $1\frac{1}{2}$ atom of acid will contain 3 atoms of oxygen, and 3 is, of course, a multiple of 1; but in acids containing 1 or 3 atoms of oxygen, the law of Berzelius cannot hold.

With respect to the subsesquisalts they will all come under Berzelius' law when the acid happens to contain 3 atoms oxygen, and the base only 1 atom; but they will deviate from it whenever the acid contains 1 or 2 atoms of oxygen.

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Upon the whole, though the subsalts and sesquisalts have not been sufficiently investigated to enable us to decide upon the point with perfect certainty; yet from what we do know, there appears sufficient evidence that Berzelius' rule cannot be considered as a general chemical law; and that we run the risk of falling into most egregious mistakes, if we make use of such a law in calculating the atomic weight and chemical constitution of the acids or bases. I pointed out some remarkable examples of this error when treating of uranium, to which it is merely necessary to refer the reader.

APPENDIX,

EXHIBITING THE

SPECIFIC GRAVITIES OF THE GASES,

AND THE

ATOMIC WEIGHTS,

DETERMINED IN THE PRECEDING CHAPTERS OF THIS WORK.

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TABLE I.

SPECIFIC GRAVITY OF THE GASES.

	SP. GRAVITY AT 60°	WEIGHT OF 100 CUBIC INCHES IN GRAINS
Air	1	30·5
Hydrogen	0·0694	2·1180
Carbon vapour	0·4166	12·6083
Carburetted Hydrogen	0·5555	16·9444
Ammonia	0·59027	18·0035
Steam	0·625	19·0620
Subphosphuretted hydrogen	0·6944	21·1805
Phosphorus vapour	0·8333	25·4166
Phosphuretted hydrogen	0·9027	27·5376
Hydrocyanic acid vapour	0·9375	28·5720
Bihydroguret of phosphorus	0·9722	29·6527
Carbonic oxide	0·9722	29·6527
Azotic gas	0·9722	29·6527
Olefiant gas	0·9722	29·6527
Deutoxide of azote	1·04166	31·7708
Oxygen	1·111	33·8888
Sulphur vapour	1·111	33·8888
Sulphuretted hydrogen	1·1805	36·0069
Muriatic acid	1·28472	39·1839
Oil gas	1·4583	44·47917
Carbonic acid	1·5277	46·5972
Protoxide of azote	1·5277	46·5972
Cyanogen	1·8055	55·0694
Sulphurous acid	2·2222	67·7777
Tellurium vapour	2·2222	67·7777
Telluretted hydrogen	2·2916	69·89583
Fluoboric acid	2·361	72·0135
Protoxide of chlorine	2·4444	74·5555
Chlorine	2·5	76·25
Arsenic vapour	2·6388	80·486
Bisulphuret of carbon vapour	2·6388	80·486
Arsenietted Hydrogen	2·7083	82·60416
Selenium vapour	2·7777	84·6980
Sulphuric acid vapour	2·7777	84·6980
Selenietted hydrogen	2·8522	86·9927
Naphtha vapour	2·9166	88·9583
Chlorocarbonic acid	3·4722	105·9020
Fluosilicic acid	3·611	110·1385
Nitric acid vapour	3·75	114·375
Hydriodic acid	4·34027	132·3785
Oil of turpentine vapour	5·0130	152·8960
Iodine vapour	8·611	262·6308

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TABLE II.

SPECIFIC GRAVITY AND ATOMIC WEIGHTS OF THE GASES REFERRED TO OXYGEN GAS AS UNITY.

I. GASES WHOSE ATOMIC WEIGHT = SPECIFIC GRAVITY.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Oxygen gas	1	1
Fluosilicic acid	3·25	3·25

II. GASES WHOSE ATOMIC WEIGHT IS DOUBLE THE SPECIFIC GRAVITY.

a. Simple Bodies.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Hydrogen gas	0·125	0·0625
Carbon vapour	0·75	0·375
Phosphorus vapour	1·5	0·75
Azotic gas	1·75	0·875
Sulphur vapour	2	1
Tellurium vapour	4	2
Chlorine gas	4·5	2·25
Arsenic vapour	4·75	2·375
Selenium vapour	5	2·5
Iodine vapour	15·5	7·75

b. Compounds of Simple Combustibles and Hydrogen.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Carburetted hydrogen	1	0·5
Phosphuretted hydrogen	1·625	0·8125
Subphosphuretted hydrogen	1·25	0·625
Bihydroguret of phosphorus	1·75	0·875
Olefiant gas	1·75	0·875
Oil gas	2·625?	1·3175?
Sulphuretted hydrogen	2·125	1·0625
Telluretted hydrogen	4·125	2·0625
Oil of turpentine	9·125?	4·5625?
Arsenietted hydrogen	4·875	2·4375
Selenietted hydregen	5·125	2·5625

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c. *Compounds of Simple Combustibles and Oxygen.*

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Steam	1·125	0·5625
Carbonic oxide gas	1·75	0·875
Carbonic acid	2·75	1·375
Protoxide of azote	2·75	1·375
Nitric acid vapour	6·75	3·375
Sulphurous acid	4	2
Sulphuric acid vapour	5	2·5

d. *Miscellaneous Compounds.*

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Cyanogen	3·25	1·625
Fluoboric acid	4·25	2·125
Bisulphuret of carbon	4·75	2·375
Chlorocarbonic acid	6·25	3·125

III. GASES WHOSE ATOMIC WEIGHT IS QUADRUPLE THE SPECIFIC GRAVITY.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Ammoniacal gas	2·125	0·53125
Hydrocyanic acid vapour	3·375	0·84375
Deutoxide of azote	3·75	0·9375
Muriatic acid	4·625	1·15625
Hydriodic acid	15·625	3·90625

TABLE III.

EXHIBITING THE ATOMIC WEIGHTS OF BODIES.

	ATOMIC WEIGHT. OXYGEN = 1	ATOMIC WEIGHT. HYDR. = 1		ATOMIC WEIGHT. OXYGEN = 1	ATOMIC WEIGHT. HYDR. = 1
Hydrogen	0·125	1	Lithium	1·25	10
Base of fluoric acid?	0·25	2	Fluoric acid	1·25	10
Carbon	0·75	6	Subphosphuretted hydrogen	1·25	10
Boron	1	8	Naphthaline	1·25	10
Silicon	1	8	Phosphorus	1·5	12
Oxygen	1	8	Magnesium	1·5	12
Carburetted hydrogen	1	8	Phosphuretted hydrogen	1·625	13
Water	1·125	9	Azote	1·75	14
Aluminum	1·25	10	Carbonic oxide	1·75	14

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Bacterium	1
Bacterium Coli	1
Bacterium Termo	1
Bacterium Typhosum	1
Bacteroids	1
Bacteroids, Nodule	1
Bacteroids, Root	1
Bacteroids, Tubercle	1
Bacteroids, Tubercle, Root	1
Bacteroids, Tubercle, Root, Nodule	1
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	ATOMIC WEIGHT. OXYGEN = 1	HYDR. = 1
Protochloride of phosphorus	6	48
Chloride of magnesium	6	48
Oxide of selenium	6	48
Protohyd. of sulphuric acid	6·125	49
Perhydrate of iron	6·125	49
Cerium	6·25	50
Sulphuret of zinc	6·25	50
Acetic acid	6·25	50
Succinic acid	6·25	50
Chlorocarbonic acid	6·25	50
Strontian	6·5	52
Sesquisulphuret of iron	6·5	52
Chromic acid	6·5	52
Protoxide of antimony	6·5	52
Manganesous acid?	6·5?	52?
Protoxide of rhodium	6·5	52
Chloride of sulphur	6·5	52
Nitric acid	6·75	54
Sulphuret of arsenic	6·75	54
Arsenious acid	6·75	54
Cadmium	7	56
Palladium	7	56
Protoxide of molybdenum	7	56
Protosulphuret of potassium	7	56
Deutoxide of antimony	7	56
Chloride of calcium	7	56
Selenic acid	7	56
Trihydrate of silica	7·125	57
Hydrate of zirconia	7·125	57
Tin	7·25	58
Protoxide of cerium	7·25	58
Citric acid	7·25	58
Acetic acid crystals	7·375	59
Peroxide of rhodium	7·5	60
Peroxide of antimony	7·5	60
Manganesic acid	7·5?	60
Chloride of sodium	7·5	60
Sulphuret of rhodium	7·5	60
Persulphuret of iron	7·5	60
Sulphuret of strontium	7·5	60
Tritoxide of chlorine	7·5	60
Antimonic acid	7·5	60
Sulphuret of antimony	7·5	60
Kermes mineral	7·625	61
Chloride of nickel	7·75	62
Arsenic acid	7·75	62
Chloride of cobalt	7·75	62
Sesquisulphuret of arsenic	7·75	62
Peroxide of cerium	7·75	62
Chlorocyanic acid	7·75	62
Gallic acid	7·75?	62?
Oxide of cadmium	8	64
Oxide of palladium	8	64
Peroxide of potassium	8	64
Chloride of iron	8	64
Chloride of manganese	8	64
Bisulphuret of copper	8	64
Molybdous acid	8	64
Sesquisulphuret of selenium	8	64
Tartaric acid	8·25	66
Protoxide of tin	8·25	66
Quadroxide of chlorine	8·5	68
Chloride of copper	8·5	68
Dichloride of sulphur	8·5	68
Chloride of zinc	8·75	70
Barium	8·75	70
Tannin	8·75?	70?
Bismuth	9	72
Molybdic acid	9	72
Uric acid	9	72
Suboxide of copper	9	72
Deutosulphuret of potass.	9	72
Peroxide of sodium	9	72
Sulphuret of cadmium	9	72
Sulphuret of palladium	9	72
Hyposulphuric acid	9	72
Oxalic acid crystals	9	72
Oil of turpentine	9·125?	73?
Peroxide of tin	9·25	74
Protosulphuret of tin	9·25	74
Tartaric acid crystals	9·375	75
Dichloride of calcium	9·5	76
Citric acid crystals	9·5	76
Chloric acid	9·5	76
Chloride of potassium	9·5	76
Barytes	9·75	78
Seleniet of arsenic	9·75	78
Oxide of bismuth	10	80
Bisulphuret of molybdenum	10	80
Disulphuret of copper	10	80
Chloride of antimony	10	80
Chloride of strontium	10	80
Sesquisulphuret of tin	10·25	82
Perchloride of phosphorus	10·5	84
Sulphuret of barium	10·75	86
Peroxide of barium	10·75?	86?
Sulphuret of bismuth	11	88
Tritosulphuret of potassium	11	88
Chloride of strontium	11	88
Fuming sulphuric acid	11·125	89
Persulphuret of tin	11·25	90
Gum	11·25	90
Uric acid crystals	11·25	90
Perchloric acid	11.5	92

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	ATOMIC WEIGHT. OXYGEN = 1	HYDR. = 1
Chloride of cadmium	11·5	92
Protochloride of tin	11·75	94
Platinum	12	96
Perchloride of iron	12·5 ?	100
Dichloride of copper	12·5	100
Persulphuret of bismuth	13	104
Quadrosulphuret of potass.	13	104
Protoxide of platinum	13	104
Lead	13	104
Saclactic acid	13	104
Chloride of barium	13·25	106
Chloride of bismuth	13·5	108
Silver	13·75	110
Protoxide of lead	14	112
Sulphuret of platinum	14	112
Peroxide of platinum	14	112
Bichloride of silenium	14	112
Deutoxide of lead	14·5	116
Oxide of silver	14·75	118
Peroxide of lead	15	120
Protosulphuret of lead	15	120
Quintosulphuret of potass.	15	120
Benzoic acid	15	120
Octohydrate of zirconia	15	120
Iodine	15·5	124
Dichloride of antimony	15·5	124
Hydriodic acid	15·625	125
Decahydrate of chlorine	15·75	126
Sulphuret of silver	15·75	126
Tungsten	15·75	126
Bisulphuret of platinum	16	128
Perchloride of tin	16·25	130
Chloride of platinum	16·5	132
Tridecahydrate of silica	16·625	133
Persulphuret of lead	17	136
Iodide of phosphorus	17	136
Chloride of lead	17·5	140
Iodide of sulphur	17·5	140
Starch	17·75	142
Oxide of tungsten	17 75	142
Columbium	18	144
Iodide of calcium	18	144
Chloride of silver	18·25	146
Iodide of sodium	18·5	148
Tungstic acid	18·75	150
Columbic acid	19	152

	ATOMIC WEIGHT. OXYGEN = 1	HYDR. = 1
Iodide of iron	19	152
Iodide of copper	19·5	156
Iodide of zinc	19·75	158
Quadrochloride of azote	19·75	158
Bisulphuret of tungsten	19·75	158
Sulphuret of columbium	20	160
Iodic acid	20·5	164
Iodide of potassium	20·5	164
Bichloride of platinum	21	168
Iodide of strontium	21	168
Suboxide of silver	21·625	173
Iodide of cadmium	22·5	180
Iodide of barium	24·25	194
Iodide of bismuth	24·5	196
Chloriodic acid	24·5	196
Gold	25	200
Mercury	25	200
Protoxide of gold	26	208
Uranium	26	208
Protoxide of mercury	26	208
Protoxide of uranium	27	216
Peroxide of mercury	27	216
Protosulphuret of mercury	27	216
Peroxide of gold	28	224
Peroxide of uranium	28	224
Sulphuret of uranium	28	224
Disulphuret of lead	28	224
Iodide of lead	28·5	228
Persulphuret of mercury	29	232
Iodide of silver	29·25	234
Chloride of mercury	29·5	236
Chloride of gold	29·5	236
Tritosulphuret of gold	31	248
Periodide of phosphorus	32·5	260
Margaric acid	33	264
26 hydrate of chromium	33·75	270
Bichloride of mercury	34	272
Bichloride of gold	34	272
Oleic acid	36	288
Triiodide of azote	37·25 ?	298
Morphia	40·25	322
Protiodide of mercury	40·5	324
Picrotoxia	45	360
Strychnia	47·5 ?	380
Brucia	51·5	412
Periodide of mercury	56	448

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TABLE IV.

EXHIBITING THE COMPOSITION AND ATOMIC WEIGHT OF THE SALTS.

I. ACETATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Of alumina	1	1	1	6·25	2·25	1·125	9·625	77
ammonia	1	1	7	6·25	2·125	7·875	16·25	130
barytes	1	1	3	6·25	9·75	3·375	19·375	155
cadmium	1	1	2	6·25	8	2·25	16·5	132
copper	1	1	1	6·25	5	1·125	12·375	99
diacetate of copper	1	2	6	6·25	10	6·75	23	184
subsesquacetate	1	1½	3	6·25	7·5	3·375	17·125	137
trisacetate	1	3	2	6·25	15	2·25	23·5	188
iron	1	1	3	6·25	4·5	3·375	14·125	113
lead	1	1	3	6·25	14	3·375	23·625	189
diacetate of lead	1	2	10	6·25	28	11·25	45·5	364
trisacetate of lead	1	3	2	6·25	42	2·25	50·5	404
lime	1	1	6	6·25	3·5	6·75	16·5	132
magnesia	1	1	5	6·25	2·5	5·625	14·375	115
manganese	1	1	4	6·25	4·5	4·5	15·25	122
mercury	1	1	4	6·25	26	4·5	36·75	294
nickel	1	1	5	6·25	4·25	5·625	16·125	129
potash	1	1	2	6.25	6	2·25	14·5	116
binacetate of potash	2	1	6	12·5	6	6·75	25·25	202
silver	1	1	0	6·25	14·75	0	21	168
soda	1	1	6	6·25	4	6·75	17	136
strontian	1	1	1	6·25	6·5	1·125	13·875	111
zinc	1	1	7	5·25	6·25	7·875	19·375	155

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II. ANTIMONIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Tritantimoniate of potash	3	1	0	22·5	6	0	28·5	228

III. ARSENIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT	
							Oxygen = 1	Hydrog. = 1
Arseniate of alumina	1	1	6	7·75	2·25	6·75	16·75	122
ammonia	1	1	0	7·75	2·125	0	9·875	79
Binarseniate of ammonia	2	1	2	15·5	2·125	2·25	19·875	159
Arseniate of bismuth	1	1	2	7·75	10	2·25	20	160
cadmium	1	1	1	7·75	8	1·125	16·875	135
cobalt	1	1	4	7·75	4·25	4·5	16·5	132
Diprotarseniate of iron	1	2	3	7·75	9	3·375	20·125	161
Arseniate of lead	1	1	0	7·75	14	0	21·75	174
Subsesquarseniate of lead	1	1½	0	7·75	21	0	28·75	230
Arseniate of lime	1	1	0	7·75	3·5	0	11·25	90
magnesia	1	1	8	7·75	2·5	9	19·25	154
manganese	1	1	10	7·75	4·5	11·25	23·5	188
mercury	1	1	0	7·75	26	0	33·75	270
nickel	1	1	6	7·75	4·25	6·75	18·75	150
Binarseniate of nickel	2	1	10	15·5	4·25	11·25	31	248
potash	2	1	1	15·5	6	1·125	22·625	181
Arseniate of soda	1	1	8	7·75	4	9	20·75	166
Binarseniate of soda	2	1	5	15·5	4	5·625	25·125	201
Arseniate of strontian	1	1	8	7·75	6·5	9	23·25	186
zinc	1	1	8	7·75	5·25	9	22	176
Subsesquarseniate of silver	1	1½	0	7·75	22·125	0	29·875	237

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Ground floor
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Third floor
Fourth floor
Fifth floor
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Seventh floor
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Ninth floor
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VII. CHLORIDES.

	ATOMS OF CHLORINE.	ATOMS OF BASE.	WEIGHT OF CHLORINE.	WEIGHT OF BASE.	ATOMIC WEIGHT OF CHLORIDE.	
					Oxy. = 1	Hyd. = 1
Protochloride of antimony	1	1	4·5	5·5	10	80
Dichloride of do.	1	2	4·5	11	15·5	124
Chloride of barium .	1	1	4·5	8·75	13·25	106
bismuth	1	1	4·5	9	13·5	108
cadmium	1	1	4·5	7	11·5	92
cerium .	1	1	4·5	6·25	10·75	86
chromium	1	1	4·5	3·5	8	64
cobalt .	1	1	4·5	3·25	7·75	62
copper .	1	1	4·5	4	8·5	68
Dichloride of do. .	1	2	4·5	8	12·5	100
Chloride of glucinum	1	1	4·5	2·25	6·75	54
gold .	1	1	4·5	25	29·5	236
Bichloride of do. .	2	1	9	25	34	272
Chloride of iron .	1	1	4·5	3·5	8	64
Sesquichloride of do.	1½	1	6·75	3·5	10·25	82
Chloride of lead .	1	1	4·5	13	17·5	140
lime .	1	1	4·5	2·5	7	56
lithium .	1	1	4·5	1·25	5·75	46
magnesium	1	1	4·5	1·5	6	48
manganese	1	1	4·5	3·5	8	64
Protochloride of mercury	1	1	4·5	25	29·5	236
Bichloride of do.	2	1	9	25	34	272
Chloride of nickel .	1	1	4·5	3·25	7·25	58
palladium	1	1	4·5	7	11·5	92
platinum	1	1	4·5	12	16·5	132
Bichloride of do. .	2	1	9	12	21	168
Chloride of potassium	1	1	4·5	5	9·5	76
rhodium	1	1	4·5	5·5	10	80
silver .	1	1	4·5	13·75	18·25	146
sodium .	1	1	4·5	3	7·5	60
strontium	1	1	4·5	5·5	10	80
tin .	1	1	4·5	7·25	11·75	94
Bichloride of do. .	2	1	9	7·25	16·25	130
Chloride of uranium	1	1	4·5	26	30·5	244
yttrium	1	1	4·5	4·25	8·75	70
zinc .	1	1	4·5	4·25	8·75	70
zirconium	1	1	4·5	5	9·5	76

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VIII. CHROMATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Chromate of ammonia	1	1	0	6·5	2·125	0	8·625	69
Bichromate of do.	2	1	2	13	2·125	2·25	17·375	139
Chromate of barytes	1	1	0	6·5	9·75	0	16·25	130
Chromate of bismuth	1	1	2	6·5	10	2·25	18·75	150
cadmium	1	1	5	6·5	8	5·625	20·125	161
chromium	1	1	0	6·5	4·5	0	11	88
cobalt	1	1	2	6·5	4·25	2·25	13	104
copper	1	1	2	6·5	5	2·25	13·75	110
lead	1	1	0	6·5	14	0	20·5	164
lime	1	1	0	6·5	3·5	0	10	80
magnesia	1	1	2	6·5	2·5	2·25	11·25	90
mercury	1	1	0	6·5	26	0	32·5	260
nickel	1	1	4	6·5	4·25	4·5	15·25	122
potash	1	1	0	6·5	6	0	12·5	100
Bichromate of do.	2	1	0	13	6	0	19	152
Chromate of silver	1	1	0	6·5	14·75	0	21·25	170
soda	1	1	12	6·5	4	13·5	24	192
strontian	1	1	0	6·5	6·5	0	13	104
zinc	1	1	0	6·5	5·25	0	11·75	94

IX. COLUMBATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Columbate of soda	1	1	10	19	4	11·25	34·25	274

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X. FLUOSILICATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Bifluosilicate of ammonia	2	1	0	6·5	2·125	0	8·625	69

XI. FLUOBORATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Fluoborate of ammonia	1	1	0	4·25	2·125	0	6·375	51
Bifluoborate of do.	2	1	0	8·5	2·125	0	10·625	85
Subsesquifluoborate of do.	1	1½	0	4·25	3·1875	0	7·4375	59½

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XII. FORMATES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Formate of copper .	1	1	4	4·625	5	4·5	14·125	113
lead .	1	1	1	4·625	14	1·125	19·75	158

XIII. HYPONITRITES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Hyponitrite of lead .	1	1	1	4·75	14	1·125	19·875	159

XIV. MOLYBDATES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Bimolybdate of ammonia	2	1	1	18	2·125	1·125	21·25	170
Molybdate of lead .	1	1	0	9	14	0	23	184

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XV. MURIATES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Muriate of alumina	1	1	3	4·625	2·25	3·375	10·25	82
ammonia	1	1	0	4·625	2·125	0	6·75	54
barytes	1	1	1	4·625	9·75	1·125	15·5	124
bismuth	1	1	x	4·625	10	x		
cadmium	1	1	1	4·625	8	1·125	13·75	110
cerium	1	1	x	4·625	7·25	x		
chromium	1	1	9	4·625	4·5	10·125	19·25	154
cobalt	1	1	4	4·625	4·25	4·5	13·375	107
copper	1	1	2	4·625	5	2·25	11·875	95
glucina	1	1	x	4·625	3·25	x		
iron	1	1	3	4·625	4·5	3·375	12·5	100
lime	1	1	6	4·625	3·5	6·75	14·875	119
lithia	1	1	x	4·625	2·25	x		
magnesia	1	1	5	4·625	2·5	5·625	12·75	102
manganese	1	1	4	4·625	4·5	4·5	13·625	109
nickel	1	1	5	4·625	4·25	5·625	14·5	116
strontian	1	1	8	4·625	6·5	9	20·125	161
Bimuriate of tin	2	1	3	9·25	9·25	3·375	21·875	213
Muriate of zinc	1	1	0	4·625	5·25	0	9·875	79
zirconia	1	1	5	4·625	6	5·625	16·25	130

XVI. NITRATES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Dinitrate of alumina	1	2	10	6·75	4·5	11·25	22·5	180
Trisnitrate of do.	1	3	6	6·75	6·75	6·75	20·25	162
Nitrate of ammonia	1	1	1	6·75	2·125	1·125	10	80

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NITRATES CONTINUED.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Nitrate of barytes .	1	1	0	6·75	9·75	0	16·5	132
bismuth .	1	1	3	6·75	10	3·375	20·125	161
Dinitrate of bismuth	1	2	2	6·75	20	2·25	29	232
Nitrate of cadmium .	1	1	4	6·75	8	4·5	19·25	154
cobalt .	1	1	6	6·75	4·25	6·75	17·75	142
copper .	1	1	7	6·75	5	7·875	19·625	157
iron .	1	1	7	6·75	4·5	7·875	19·125	153
Persesquinitrate of iron	1½	1	8	10·125	5	9	24·125	193
lead	1	1	0	6·75	14	0	20·75	166
lime	1	1	6	6·75	3·5	6·75	17	136
magnesia	1	1	6	6·75	2·5	6·75	16	128
manganese	1	1	7	6·75	4·5	7·875	19·125	153
mercury	1	1	2	6·75	26	2·25	35	280
Pernitrate of mercury	1	1	0	6·75	27	0	33·75	270
Nitrate of nickel .	1	1	5	6·75	4·25	5·625	16·625	133
potash .	1	1	0	6·75	6	0	12·75	102
silver .	1	1	0	6·75	14·75	0	21·5	172
soda .	1	1	0	6·75	4	0	10·75	86
strontian .	1	1	4	6·75	6·5	4·5	17·75	142
do. (anhydrous)	1	1	0	6·75	6·5	0	13·25	106
Sesquinitrate of uranium	1½	1	17	10·125	28	19·125	57·25	458
Nitrate of zinc .	1	1	6	6·75	5·25	6·75	18·75	140

XVII. NITRITES.

	Atoms of Acid.	Atoms of Base.	Atoms of Water.	Weight of Acid.	Weight of Base.	Weight of Water.	Atomic Weight of Salt.	
							Oxygen = 1	Hydrog. = 1
Dinitrite of lead .	1	2	2	5·75	230	2·25	80	288

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XVIII. OXALATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Oxalate of alumina	1	1	3	4·5	2·25	3·375	10·125	81
ammonia	1	1	2	4·5	2·125	2·25	8·875	71
Binoxalate of do.	2	1	8	9	2·125	9	20·125	161
Oxalate of barytes	1	1	3	4·5	9·75	3·375	17·625	141
Binoxalate of do.	2	1	3	9	9·75	3·375	22·125	177
Oxalate of bismuth	1	1	0	4·5	10	0	14·5	116
cadmium	1	1	3	4·5	8	3·375	15·875	127
cobalt	1	1	2	4·5	4·25	2·25	11	88
copper	1	1	1	4·5	5	1·125	10·625	85
iron	1	1	2	4·5	4·5	2·25	11·25	90
lead	1	1	0	4·5	14	0	18·5	148
lime	1	1	2	4·5	3·5	2·25	10·25	82
magnesia	1	1	2	4·5	2·5	2·25	9·25	74
Binoxalate of do.	2	1	7	9	2·5	7·875	19·375	155
Oxalate of manganese	1	1	3	4·5	4·5	3·375	12·375	99
mercury	1	1	1	4·5	26	1·125	31·625	253
nickel	1	1	4	4·5	4·25	4·5	13·25	106
potash	1	1	1	4·5	6	1·125	11·625	93
Binoxalate of do.	2	1	2	9	6	2·25	17·25	138
Quadroxalate of do.	4	1	7	18	6	7·875	31·875	255
Oxalate of silver	1	1	0	4·5	14·75	0	19·25	154
soda	1	1	0	4·5	4	0	6·5	68
Binoxalate of do.	2	1	3	9	4	3·375	16·375	131
Oxalate of strontian	1	1	2	4·5	6·5	2·25	13·25	106
Binoxalate of do.	2	1	0	9	6·5	0	15·5	124
Teroxalate of uranium	3	1	0	13·5	28	0	11·5	332
Oxalate of zinc	1	1	2	4·5	5·25	2·25	12	96

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XIX. OXIDES.

	Atoms of Oxygen.	Atoms of Base.	Weight of Oxygen.	Weight of Base.	Atomic Weight of Oxides.	
					Oxy. = 1	Hyd. = 1
Oxide of aluminum	1	1	1	1·25	2·25	18
Antimony, protoxide	1	1	1	5·5	6·5	52
deutoxide	1·5	1	1·5	5·5	7	56
peroxide	2	1	2	5·5	7·5	60
Barium, protoxide	1	1	1	8·75	9·75	78
peroxide	2	1	2	8·75	10·75	86
Bismuth, oxide	1	1	1	9	10	80
Cadmium, do.	1	1	1	7	8	64
Calcium, do.	1	1	1	2·5	3·5	28
Cerium, protoxide	1	1	1	6·25	7·25	58
peroxide	1·5	1	1·5	6·25	7·75	62
Chromium, protoxide	1	1	1	3·5	4·5	36
deutoxide	2	1	2	3·5	5·5	44
acid	3	1	3	3·5	6·5	52
Cobalt, protoxide	1	1	1	3·25	4·25	34
peroxide	1·5	1	1·5	3·25	4·75	38
Copper, suboxide	1	2	1	8	9	72
oxide	1	1	1	4	5	40
Glucinum, oxide	1	1	1	2·25	3·25	26
Gold, protoxide	1	1	1	25	26	208
tritoxide	3	1	3	25	28	224
Iron, protoxide	1	1	1	3·5	4·5	36
peroxide	1·5	1	1·5	3·5	5	40
Lead, protoxide	1	1	1	13	14	112
deutoxide	1·5	1	1·5	13	14·5	116
peroxide	2	1	2	13	15	120
Lithium, oxide	1	1	1	1·25	2·25	18
Magnesium, oxide	1	1	1	1·5	2·5	20
Manganese, suboxide	1	2	1	7	8	64
oxide	1	1	1	3·5	4·5	36
deutoxide	1·5	1	1·5	3·5	5	40
tritoxide	2	1	2	3·5	5·5	44
Manganesous acid?	3?	1	3	3·5	6·5	52
Manganesic acid	4	1	4	3·5	7·5	60
Mercury, protoxide	1	1	1	25	26	208
peroxide	2	1	2	25	27	216
Nickel, protoxide	1	1	1	3·25	4·25	34
peroxide	1·5	1	1·5	3·25	4·75	38
Palladium, oxide	1	1	1	7	8	64
Platinum, protoxide	1	1	1	12	13	104
peroxide	2	1	2	12	14	112
Potassium, protoxide	1	1	1	5	6	48
peroxide	3	1	3	5	8	64
Rhodium, protoxide	1	1	1	5·5	6·5	52
peroxide	2	1	2	5·5	7·5	60
Silver, oxide	1	1	1	13·75	14·75	118
Sodium, oxide	1	1	1	3	4	32
peroxide	1·5	1	1·5	3	4·5	36
Strontium, oxide	1	1	1	5·5	6·5	52
Tin, protoxide	1	1	1	7·25	8·25	66
peroxide	2	1	2	7·25	9·25	74
Uranium, protoxide	1	1	1	26	27	216
peroxide	2	1	2	26	28	224
Yttrium, oxide	1	1	1	4·25	5·25	42
Zinc, oxide	1	1	1	4·25	5·25	42
Zirconium, oxide	1	1	1	5	6	48

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XX. PHOSPHATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Phosphate of alumina	1	1	3	3·5	2·25	3·375	9·125	73
ammonia	1	1	2	3·5	2·125	2·25	7·875	63
Biphosphate of do.	2	1	0	7	2·125	0	9·125	73
Phosphate of barytes	1	1	0	3·5	9·75	0	13·25	106
bismuth	1	1	3	3·5	10	3·375	16·875	135
cadmium	1	1	1	3·5	8	1·125	12·625	101
cobalt	1	1	2	3·5	4·25	2·25	10	80
copper	1	1	1	3·5	5	1·125	9·625	77
Ditto, anhydrous	1	1	0	3·5	5	0	8·5	68
Phosphate of iron	1	1	3	3·5	4·5	3·375	11·375	91
Pertrisphosphate of iron	1	3	3	3·5	15	3·375	21·875	175
Phosphate of lead	1	1	0	3·5	14	0	17·5	140
Diphosphate of do.	1	2	0	3·5	28	0	31·5	252
Phosphate of lime	1	1	0	3·5	3·5	0	7	56
Apatite	1	1½	0	3·5	5·25	0	8·75	70
Phosphate of magnesia	1	1	7	3·5	2·5	7·875	13·875	111
mercury	1	1	0	3·5	26	0	29·5	236
nickel	1	1	3	3·5	4·25	3·375	11·125	89
potash	1	1	1	3·5	6	1·125	10·625	85
soda	1	1	12	3·5	4	13·5	21	168
Biphosphate of do.	2	1	3½	7	4	3·9375	14·9375	119·5
Phosphate of strontian	1	1	1	3·5	6·5	1·125	11·125	89
Biphosphate of do.	2	1	2	7	6·5	2·25	15·75	146
Phosphate of zinc	1	1	2	3·5	5·25	2·25	11	88

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XXI. SACLACTATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Saclactate of ammonia	1	1	1	13	2·125	1·125	16·25	130
soda .	1	1	5	13	4	5·625	22·625	181

XXII. SELENIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Seleniate of soda .	1	1	x	7	4	x		
Biseleniate of do. .	2	1	x	14	4	x		
Seleniate of barytes .	1	1	x	7	9·75	x		
Biseleniate of do. .	2	1	x	14	9·75	x		

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Ground Floor Plan
First Floor Plan
Second Floor Plan
Third Floor Plan
Fourth Floor Plan
Fifth Floor Plan
Sixth Floor Plan
Seventh Floor Plan
Eighth Floor Plan
Ninth Floor Plan
Tenth Floor Plan
Eleventh Floor Plan
Twelfth Floor Plan
Thirteenth Floor Plan
Fourteenth Floor Plan
Fifteenth Floor Plan
Sixteenth Floor Plan
Seventeenth Floor Plan
Eighteenth Floor Plan
Nineteenth Floor Plan
Twentieth Floor Plan
Twenty-first Floor Plan
Twenty-second Floor Plan
Twenty-third Floor Plan
Twenty-fourth Floor Plan
Twenty-fifth Floor Plan
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Twenty-seventh Floor Plan
Twenty-eighth Floor Plan
Twenty-ninth Floor Plan
Thirtieth Floor Plan
Thirty-first Floor Plan
Thirty-second Floor Plan
Thirty-third Floor Plan
Thirty-fourth Floor Plan
Thirty-fifth Floor Plan
Thirty-sixth Floor Plan
Thirty-seventh Floor Plan
Thirty-eighth Floor Plan
Thirty-ninth Floor Plan
Fortieth Floor Plan
Forty-first Floor Plan
Forty-second Floor Plan
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Forty-seventh Floor Plan
Forty-eighth Floor Plan
Forty-ninth Floor Plan
Fiftieth Floor Plan
Fifty-first Floor Plan
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Fifty-seventh Floor Plan
Fifty-eighth Floor Plan
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Sixtieth Floor Plan
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Sixty-seventh Floor Plan
Sixty-eighth Floor Plan
Sixty-ninth Floor Plan
Seventieth Floor Plan
Seventy-first Floor Plan
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Seventy-sixth Floor Plan
Seventy-seventh Floor Plan
Seventy-eighth Floor Plan
Seventy-ninth Floor Plan
Eightieth Floor Plan
Eighty-first Floor Plan
Eighty-second Floor Plan
Eighty-third Floor Plan
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Eighty-sixth Floor Plan
Eighty-seventh Floor Plan
Eighty-eighth Floor Plan
Eighty-ninth Floor Plan
Ninetieth Floor Plan
Ninety-first Floor Plan
Ninety-second Floor Plan
Ninety-third Floor Plan
Ninety-fourth Floor Plan
Ninety-fifth Floor Plan
Ninety-sixth Floor Plan
Ninety-seventh Floor Plan
Ninety-eighth Floor Plan
Ninety-ninth Floor Plan
One Hundredth Floor Plan

XXV. SULPHATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Sulphate of alumina	1	1	7	5	2·25	7·875	15·125	121
Disulphate of do.	1	2	x	5	4·5	x		
Trisulphate of do.	1	3	9	5	6·75	10·125	21·875	215
Sulphate of ammonia	1	1	1	5	2·125	1·125	8·25	66
barytes	1	1	0	5	9·75	0	14·75	118
bismuth	1	1	0	5	10	0	15	120
cadmium	1	1	4	5	8	4·5	17·5	140
Ditto, in crusts	1	1	2	5	8	2·25	15·25	122
Sulphate of cerium	1	1	3	5	7·25	3·375	15·625	125
cobalt	1	1	7	5	4·25	7·875	17·125	137
Bisulphate of do.	2	1	3	10	4·25	3·375	17·625	141
Sulphate of copper	1	1	5	5	5	5·625	15·625	125
Bisulphate of glucina	2	1	5	10	3·25	5·625	18·875	151
Sulphate of iron	1	1	7	5	4·5	7·875	17·375	139
Persesquisulphate of iron	1½	1	x	7·5	5			
Sulphate of lead	1	1	0	5	14	0	19	152
lime	1	1	2	5	3·5	2·25	10·75	86
Ditto, anhydrous	1	1	0	5	3·5	0	8·5	68
Sulphate of lithia	1	1	1	5	2·25	1·125	8·375	67
magnesia	1	1	7	5	2·5	7·875	15·375	123
manganese	1	1	5	5	4·5	5·625	15·125	121
mercury	1	1	2	5	26	2·25	33·25	266
Persulphate of do.	1	1	0	5	27	0	32	256
Sulphate of nickel	1	1	7	5	4·25	7·875	17·125	137
platinum	1	1	0	5	14	0	19	152
potash	1	1	0	5	6	0	11	88
Bisulphate of do.	2	1	2	10	6	2·25	18·25	146
Sulphate of silver	1	1	0	5	14·75	0	19·75	158
soda	1	1	10	5	4	11·25	20·25	162
strontian	1	1	0	5	6·5	0	11·5	92
Sesquisulphate of uranium	1·5	1	4	7·5	28	4·5	40	320
Sulphate of yttria	1	1	x	5	3·25	x		
[illegible]	1	1	7	5	[illegible]	7·875	[illegible]	[illegible]

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XXVI. SULPHURETS.

	Atoms of Sulphur.	Atoms of Base.	Weight of Sulphur.	Weight of Base.	Atomic Weight of Sulphurets.	
					Oxy. = 1	Hyd. = 1
Arsenic, sulphuret	1	1	2	4·75	6·75	54
sesquisulphuret	1½	1	3	4·75	7·75	62
Sulphuret of antimony	1	1	2	5·5	7·5	60
barium	1	1	2	8·75	10·75	86
bismuth	1	1	2	9	11	88
cadmium	1	1	2	7	9	72
calcium	1	1	2	2·5	4·5	36
cerium	1	1	2	6·25	8·25?	66?
chromium	1	1	2	3·5	5·5	44
cobalt	1	1	2	3·25	5·25	42
Columbium, sulphuret	1	1	2	18	20	160
Copper, disulphuret	1	2	2	8	10	80
sulphuret	1	1	2	4	6	48
bisulphuret	2	1	4	4	8	64
Gold, tritosulphuret	3	1	6	25	31	248
Iron, sulphuret	1	1	2	3·5	5·5	44
sesquisulphuret	1½	1	3	3·5	6·5	52
bisulphuret	2	1	4	3·5	7·5	60
Lead, disulphuret	1	2	2	26	28	224
sulphuret	1	1	2	13	15	120
bisulphuret	2	1	4	13	17	136
Lithium, sulphuret	1	1	2	1·25	3·25?	26?
Magnesium, do.	1	1	2	1·5	3·5	28
Manganese, do.	1	1	2	3·5	5·5	44
Mercury, do.	1	1	2	25	27	216
bisulphuret	2	1	4	25	29	232
Nickel, sulphuret	1	1	2	3·25	5·25	42
Palladium, do.	1	1	2	7	9	72
Platinum, do.	1	1	2	12	14	112
bisulphuret	2	1	4	12	16	128
Potassium, protosulphuret	1	1	2	5	7	56
deutosulphuret	2	1	4	5	9	72
tritosulphuret	3	1	6	5	11	88
quadrosulphuret	4	1	8	5	13	104
quintosulphuret	5	1	10	5	15	120
Rhodium, sulphuret	1	1	2	5·5	7·5	60
Silver, do.	1	1	2	13·75	15·75	126
Sodium, do.	1	1	2	3	5	40
Strontium, do.	1	1	2	5·5	7·5	60
Tin, do.	1	1	2	7·25	9·25	74
sesquisulphuret	1·5	1	3	7·25	10·25	82
bisulphuret	2	1	4	7·25	11·25	90
Titanium, sulphuret	1	1	2	4	6	48
Uranium, do.	1	1	2	26	28	224
Zinc, do.	1	1	2	4·25	6·25	50

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XXVII. TARTRATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Tartrate of alumina	1	1	1	8·25	2·25	1·125	11·625	93
ammonia	1	1	0	8·25	2·125	0	10·375	83
barytes	1	1	0	8·25	9·75	0	18	144
bismuth	1	1	5	8·25	10	5·625	23·875	191
cadmium	1	1	2	8·25	8	2·25	18·5	148
cobalt	1	1	2	8·25	4·25	2·25	14·75	116
copper	1	1	3	8·25	5	3·375	16·625	133
iron	1	1	2	8·25	4·5	2·25	15	120
lead	1	1	0	8·25	14	0	22·25	178
lime	1	1	4	8·25	3·5	4·5	16·25	130
magnesia	1	1	2	8·25	2·5	2·25	13	104
Bitartrate of do.	2	1	1	16·5	2·5	1·125	20·125	161
Tartrate of manganese	1	1	2	8·25	4·5	2·25	15	120
mercury	1	1	0	8·25	26	0	34·25	284
nickel	1	1	0	8·25	4·25	0	12·5	100
potash	1	1	2	8·25	6	2·25	16·5	132
Bitartrate of do.	2	1	2	16·5	6	2·25	24·75	198
Tartrate of silver	1	1	0	8·25	14·75	0	23	184
soda	1	1	2	8·25	4	2·25	14·5	116
strontian	1	1	3	8·25	6·5	3·375	18·125	145
zinc	1	1	0	8·25	5·25	0	13·5	108

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XXVIII. TITANIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Quintotitaniate of potash	5	1	0	30	6	0	36	288
Trititaniate of soda .	3	1	2	18	4	2·25	24·25	194

XXIX. TUNGSTATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Bitungstate of ammonia	2	1	2	37·5	2·125	2·25	41·875	335
Tungstate of lead .	1	1	0	18·75	14	0	32·75	262
Bitungstate of do. .	2	1	0	37·5	14	0	51·5	412
Tungstate of soda .	1	1	6	18·75	4	6·75	29·5	236

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XXX. URANIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Sesquiuranniate of barytes	1·5	1	0	42	9·75	0	51·75	414
Biuranniate of potash	2	1	3	56	6	3·375	65·375	523

XXXI. URATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Urate of soda .	1	1	1	9	4	1·125	14·125	113

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TABLE V.

COMPOUND SALTS.

I. AMMONIACAL COMPOUND SALTS.

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
1. *Ammonio-Sulphate of Alumina.*			
3 atoms sulphate of alumina	21·75		
1 atom sulphate of ammonia	7·125		
25 atoms water	28·125		
		57	456
2. *Ammonio-Sulphate of Copper.*			
1 atom sulphate of copper	10		
1 atom sulphate of ammonia	7·125		
6 atoms water	6·75		
		23·875	191
3. *Ammonio-Persesquisulphate of Iron.*			
2 atoms persesquisulphate of iron	25		
1 atom sulphate of ammonia	7·125		
25 atoms water	28·125		
		60·25	482
4. *Ammonio-Sulphate of Magnesia.*			
1 atom sulphate of magnesia	7·5		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875?		
		22·5	180
5. *Ammonio-Sulphate of Manganese.*			
1 atom sulphate of manganese	9·5		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875		
		24·5	196
6. *Ammonio-Sulphate of Nickel.*			
1 atom sulphate of nickel	9·25		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875		
		24·25	194

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	ATOMIC WEIGHTS	
	Oxy. = 1	Hyd. = 1
7. *Ammonio-Sulphate of Potash.*		
1 atom sulphate of potash	11	
1 atom sulphate of ammonia	7·125	
4 atoms water	4·5	
	22·625	161
8. *Ammonio-Sulphate of Soda.*		
1 atom sulphate of soda	9	
1 atom sulphate of ammonia	7·125	
6 atoms water	6·75	
	22·875	183
9. *Ammonio-Sulphate of Zinc.*		
1 atom sulphate of zinc	10·25	
1 atom sulphate of ammonia	7·125	
7 atoms water	7·875	
	25·25	202
10. *Ammonio-Carbonate of Uranium.*		
1 atom carbonate of uranium	30·75	
3 atoms carbonate of ammonia	14·625	
4 atoms water	4·5	
	49·875	399
11. *Ammonio-Phosphate of Magnesia.*		
1 atom phosphate of magnesia	6	
1 atom phosphate of ammonia	5·625	
4 atoms water	4·5	
	16·125	129
12. *Ammonio-Phosphate of Soda.*		
1 atom phosphate of soda	7·5	
1 atom phosphate of ammonia	5·625	
16 atoms water	18	
	31·125	249
13. *Ammonio-Arseniate of Soda.*		
1 atom arseniate of soda	11·75	
1 atom arseniate of ammonia	9·875	
8 atoms water	9·000	
	30·625	245
14. *Ammonio-Muriate of Copper.*		
2 atoms muriate of copper	19·25	
1 atom muriate of ammonia	6·75	
9 atoms water	10·125	
	36·125	289

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		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
15. *Ammonio-Permuriate of Iron.*			
1 atom sesquipermuriate of iron	11·9375		
1 atom muriate of ammonia	6·75		
		18·6875	149½
16. *Ammonio-Muriate of Platinum.*			
1 atom bichloride of platinum	21		
1 atom muriate of ammonia	6·75		
		27·75	222
17. *Ammonio-Oxalate of Copper.*			
1 atom oxalate of copper	9·5		
1 atom oxalate of ammonia	6·625		
3 atoms water	3·375		
		19·5	156
18. *Ammonio-Oxalate of Copper.*			
1 atom oxalic acid	4·5		
1 atom oxide of copper	5		
1 atom ammonia	2·125		
1 atom water	1·125		
		12·75	102
19. *Ditto, Pulverulent.*			
1 atom oxalate of ammonia	6·625		
1 atom dioxalate of copper	14·5		
		21·125	169

II. POTASH COMPOUND SALTS.

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
1. *Alum.*			
3 atoms sulphate of alumina	21·75		
1 atom sulphate of potash	11		
25 atoms water	28·125		
		60·875	487
2. *Potash-Trisulphate of Alumina.*			
3 atoms trisulphate of alumina	35·25		
1 atom sulphate of potash	11		
9 atoms water	10·125		
		56·375	451

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		ATOMIC WEIGHTS	
		Oxy. = 1	Hyd. = 1
3. *Potash-Sulphate of Copper.*			
1 atom sulphate of potash	11		
1 atom sulphate of copper	10		
6 atoms water	6·75		
		27·75	222
4. *Potash-Protosulphate of Iron.*			
1 atom protosulphate of iron	9·5		
1 atom sulphate of potash	11		
5 atoms water	5·625		
		26·125	09
5. *Potash-Sesquisulphate of Iron.*			
2 atoms persesquisulphate of iron	25		
1 atom sulphate of potash	11		
25 atoms water	28·125		
		64·125	513
6. *Potash-Persulphate of Iron.*			
1 atom persulphate of iron	10		
1 atom sulphate of potash	11		
2 atoms water	2·25		
		23·25	186
7. *Potash-Sulphate of Magnesia.*			
1 atom sulphate of potash	11		
1 atom sulphate of magnesia	7·5		
7 atoms water	7·875		
		26·375	211
8. *Potash-Sulphate of Manganese.*			
1 atom sulphate of potash	11		
1 atom sulphate of manganese	9·5		
5 atoms water	5·625		
		26·125	209
9. *Potash-Sulphate of Nickel.*			
1 atom sulphate of potash	11		
1 atom sulphate of nickel	9·25		
6 atoms water	6·75		
		27	216
10. *Potash-Sulphate of Zinc.*			
1 atom sulphate of potash	11		
1 atom sulphate of zinc	10·25		
7 atoms water	7·875		
		29 125	233

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		ATOMIC WEIGHTS. Oxy. = 1	Hyd. = 1
11. *Potash-Persesquisulphate of Uranium.*			
1 atom persesquisulphate of uranium	35·5		
1 atom sulphate of potash	11		
4 atoms water	4·5		
		51	408
12. *Potash-Carbonate of Magnesia.*			
1 atom bicarbonate of potash	11·5		
2 atoms carbonate of magnesia	10·5		
9 atoms water	10·125		
		32·125	257
13. *Potash-Oxalate of Copper.*			
1 atom oxalate of potash	10·5		
1 atom oxalate of copper	9·5		
4 atoms water	4·5		
		24·5	196
14. *Ditto, in Oblique Prisms.*			
1 atom oxalate of potash	10·5		
1 atom oxalate of copper	9·5		
2 atoms water	2·25		
		22·25	178
15. *Potash-Phosphate of Soda.*			
1 atom phosphate of potash	9·5		
1 atom phosphate of soda	7·5		
15 atoms water	16·875		
		33·875	271
16. *Potash-Arseniate of Soda.*			
1 atom arseniate of potash	13·75		
1 atom arseniate of soda	11·75		
18 atoms water	20·25		
		45·75	376
17. *Potash-Tartrate of Soda.*			
1 atom tartrate of potash	14·25		
1 atom tartrate of soda	12·25		
8 atoms water	9		
		35·5	284
18. *Tartar Emetic.*			
2 atoms tartaric acid	16·5		
3 atoms protoxide of antimony	19·5		
1 atom potash	6		
2 atoms water	2·25		
		44·25	354

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		ATOMIC WEIGHTS	
		Oxy. = 1	Hyd. = 1
19. *Sulpho-Chromate of Potash.*			
6 atoms sulphate of potash	66		
1 atom chromate of potash	12·5		
		78·5	628
20. *Potash-Muriate of Palladium.*			
1 atom muriate of palladium	12·625		
1 atom muriate of potash	10·625		
1 atom water	1·125		
		24·375	195
21. *Potassium-Chloride of Platinum.*			
1 atom bichloride of platinum	21		
1 atom chloride of potassium	9·5		
		30·5	244

III. COMPOUND SALTS, WITHOUT POTASH OR AMMONIA.

		ATOMIC WEIGHTS	
		Oxy. = 1	Hyd. = 1
1. *Boro-Tartrate of Potash and Soda.*			
1 atom biborate of soda	10		
2 atoms bitartrate of potash	22·5		
12 atoms water	13·5		
		46	368
2. *Calcareo-Acetate of Copper.*			
1 atom acetate of lime	9·75		
1 atom acetate of copper	11·25		
6 atoms water	6·75		
		27·75	222
3. *Carbo-Tartrate of Alumina and Soda.*			
1 atom tartrate of alumina	10·5		
1 atom carbonate of soda	6·75		
9 atoms water	10·125		
		27·375	219
4. *Magnesio-Carbonate of Lime.*			
1 atom carbonate of lime	6·25		
1 atom carbonate of magnesia.	5·35		
		11·5	92

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		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
5. *Ditto in Crystals*—Bitter Spar.			
2 atoms carbonate of lime	12·5		
1 atom carbonate of magnesia	5·25		
		17·75	142
6. *Soda-Oxalate of Copper.*			
1 atom oxalate of soda	8·5		
1 atom oxalate of copper	9·5		
2 atoms water	2·25		
		20·25	162
7. *Soda-Sulphate of Lime.*			
1 atom sulphate of lime	8·5		
1 atom sulphate of soda	9·0		
		17·5	140
8. *Soda-Sulphate of Alumina.*			
3 atoms sulphate of alumina	21·75		
1 atom sulphate of soda	9		
25 atoms water	28·125		
		58·875	471
9. *Sodium-Chloride of Gold.*			
1 atom bichloride of gold	34		
1 atom chloride of sodium	7·5		
8 atoms water	9		
		50·5	404
10. *Sodium-Chloride of Platinum.*			
1 atom bichloride of platinum	21		
1 atom chloride of sodium	7·5		
8 atoms water	9		
		37·5	300
11. *Soda-Muriate of Rhodium.*			
1 atom permuriate of rhodium	12·125		
1 atom common salt	7·5		
8 atoms water	9		
		28·625	229

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TABLE VI.

EXHIBITING THE SUBSTANCES IN THE THREE PRECEDING TABLES, ARRANGED ALPHABETICALLY.

A	ATOMIC WEIGHTS. Oxy. = 1
Acetate of alumina	9·625
ammonia	16·25
barytes	19·375
cadmium	16·5
copper	12·375
iron	14·125
lead	23·625
lime	16·5
magnesia	14·375
manganese	15·25
mercury	36·75
nickel	16·125
potash	14·5
silver	21
soda	17
strontian	13·875
zinc	19·375
Acetic acid	6·25
Ditto, in crystals	7·375
Alcohol	2·875
Alum	60·875
Alumina	2·25
Aluminum	1·25
Ammonia	2·125
Ammonio-carbonate of uranium	49·875
Ammonio-muriate of copper	36·125
Ammonio-permuriate of iron	18·6875
Ammonio-muriate of platinum	27·75
Ammonio-oxalate of copper	19·625
Ammonio-oxalate of copper	12·75
Ammonio-persesquisulphate of iron	59·125
Ammonio-phosphate of magnesia	16·125
Ammonio-phosphate of soda	31·125
Ammonio-sulphate of alumina	59·25
Ammonio-sulphate of copper	23·875
Ammonio-sulphate of magnesia	22·5
Ammonio-sulphate of manganese	24·5
Ammonio-sulphate of nickel	24·25
Ammonio-sulphate of potash	22·625
Ammonio-sulphate of soda	22·875
Ammonio-sulphate of zinc	25·25

	ATOMIC WEIGHTS. Oxy. = 1
Antimonic acid	7·5
Antimony	5·5
Apatite	8·75
Arseniate of alumina	16·75
ammonia	9·875
bismuth	20
cadmium	16·875
cobalt	16·5
lead	21·75
lime	11·25
magnesia	19·25
manganese	23·5
mercury	33·75
nickel	18·75
Subsesquarseniate of silver	29·875
Arseniate of strontian	23·25
zinc	22
Arsenic	4·75
Arsenic acid	7·75
Arsenietted hydrogen	4·875
Arsenious acid	6·75
Azote	1·75

B	
Barium	8·75
Barytes	9·75
Bichloride of mercury	34
platinum	21
selenium	14
tin	16·25
Benzoate of ammonia	18·25
lead	30·125
potash	24·375
Benzoic acid	15
Bicarbonate of ammonia	8·75
potash	12·625
soda	10·625
Bichromate of ammonia	17·375
potash	19
Bifluoborate of ammonia	10·625
Bifluosilicate of ammonia	9·625

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	ATOMIC WEIGHTS. Oxy. = 1
Bihydrate of alumina .	4·5
Bihydroguret of phosphorous	1·75
Bimuriate of tin . .	21·875
Binarseniate of ammonia	19·875
nickel .	31
potash .	22·625
soda .	43·125
Binoxalate of ammonia .	20·125
barytes .	22·125
magnesia .	19·375
potash .	17·25
soda .	16·375
strontian .	15·5
Biphosphate of ammonia	7·875
strontian	15·75
Biseleniate of soda .	18
barytes .	23·75
Bisilicate of lime .	7·5
magnesia .	8·5
Bisulphate of cobalt .	17·625
glucina .	18·875
potash .	18·25
Bismuth . . .	9
Bisulphuret of carbon .	4·75
copper .	8
iron .	7·5
molybdenum	10
lead .	17
mercury .	29
platinum	16
tin .	11·25
tungsten .	19·75
Bitartrate of magnesia .	20·125
potash .	24·75
Bitter spar . .	17·75
Bitungstate of ammonia	41·875
lead .	51·5
Boracic acid . .	5
Boron . . .	1
Boro-tartrate of potash and soda	32·5
Brucia . . .	51·5

C

Cadmium . .	7
Calcareo-acetate of copper	27·75
Calcium . . .	2·5
Carbo-tartrate of alumina and soda . .	27·375
Carbon . . .	0·75
Carbonate of ammonia .	3·875
barytes .	12·5
cadmium .	10·75
cobalt .	8·125
iron .	7·25
lead .	16·75
lime .	6·25
lithia .	5
magnesia .	8·625
manganese	9·5
nickel .	10·375
potash .	11
silver .	17·5
soda .	18
strontian .	9·25
uranium .	31·875
yttria .	9·125
zinc .	9·125
Carbonic acid . .	2·75
oxide . .	1·75
Carburetted hydrogen .	1
Cerium . . .	6·25
Chloric acid . .	9·5
Chloride of antimony .	10
barium	13·25
bismuth .	13·5
cadmium .	11·5
cerium .	10·75
chromium .	8
cobalt .	7·75
copper .	8·5
glucinum .	6·75
gold .	29·5
iron .	8
lead .	17·5
lime .	7
lithium .	5·75
magnesium .	6
manganese .	8
mercury .	29·5
nickel .	7·25
palladium .	11·5
platinum .	16·5
potassium .	9·5
rhodium .	10
silver .	18·25
sodium .	7·5
strontium .	10
sulphur .	6·5
tin . .	11·75
uranium .	30·5
yttrium .	8·75

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	ATOMIC WEIGHTS. Oxy. = 1
Chloride of zinc	8·75
zirconium	9·5
Chlorocarbonic acid	6·25
Chlorocyanic acid	7·75
Chlorine	4·5
Chloriodic acid	24·5
Chromate of ammonia	8·625
barytes	16·25
bismuth	18·75
cadmium	20·125
chromium	11
cobalt	13
copper	13·75
lead	20·5
lime	10
magnesia	11·25
mercury	32·5
nickel	15·25
potash	12·5
silver	21·25
soda	24
strontian	13
zinc	11·75
Chromic acid	6·5
Chromium	3·5
Citric acid	7·25
Ditto, in crystals	9·5
Cobalt	3·25
Columbate of soda	34·25
Columbic acid	19
Columbium	18
Copper	4
Cubic pyrites	7·5
Cyanogen	3·25
D	
Decahydrate of chlorine	15·75
Deutosulphuret of potassium	9
Deutoxide of azote	3·75
chromium	5·5
hydrogen	2·125
lead	14·5
manganese	5
Diacetate of copper	23
lead	34·25
Dicarbonate of copper	13·875
Dichloride of antimony	15·5
copper	12·5
Dihydrate of silica	5·125
Dinitrite of lead	36
Dinitrate of alumina	22·5
bismuth	20
Diprotarseniate of iron	20·125
Diphosphate of lead	31·5
Disulphate of alumina	9·5
Disulphuret of copper	10
lead	28
E	
Ether, sulphuric	4·625
F	
Fluoborate of ammonia	6·375
Fluoboric acid	4·25
Fluoric acid?	1·25
Fluorine?	2·25
Fluosilicic acid	5·25
Formate of copper	14·125
lead	19·75
Formic acid	4·625
Fuming sulphuric acid	11·125
G	
Gallic acid	7·75?
Glucina	3·25
Glucinum	2·25
Gold	25
Gum	11·25
H	
Hydrate of alumina	3·375
silica	3·125
zirconia	7·125
Hydriodic acid	15·625
Hydrocyanic acid	3·375
Hydrogen	0·125
Hyponitrite of lead	19·375
Hyponitrous acid	4·75
Hyposulphuric acid	9
Hyposulphurous acid	8
I	
Iodic acid	20·5

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	ATOMIC WEIGHTS. Oxy. = 1
Iodide of barium	24·25
bismuth	24·5
cadmium	22·5
calcium	18
copper	19·5
iron	19
lead	28·5
phosphorus	17
potassium	20·5
silver	29·25
sodium	18·5
strontium	21
sulphur	17·5
zinc	19·75
Iodine	15·5
Iridium	5·75
Iron	3·5

K

Kermes mineral	7·625

L

Lactic acid	5·75?
Lead	13
Lime	3·5
Lithia	2·25
Lithium	1·25

M

Magnesia	2·5
Magnesio-carbonate of lime	11·5
Magnesium	1·5
Manganese	3·5
Manganesic acid	7·5?
Manganesous acid	6·5?
Margaric acid	33
Mercury	25
Molybdate of ammonia	21·25
lead	23
Molybdenum	6
Molybdic acid	9
Molybdous acid	8
Morphia	40·25
Muriate of alumina	10·25
ammonia	6·75
barytes	15·5
cadmium	13·75
chromium	19·25
cobalt	13·375
copper	11·875
glucina	7·875
iron	12·5
lime	14·875
lithia	6·875
magnesia	12·75
manganese	13·625
nickel	14·5
strontian	20·125
zinc	9·875
zirconia	16·25
Muriatic acid	4·625

N

Naphtha	5·25
Naphthaline	1·25
Nephrin	5·75
Nickel	3·25
Nitrate of ammonia	10
barytes	16·5
bismuth	20·125
cadmium	19·25
cobalt	17·75
copper	19·625
iron	19·125
lead	20·75
lime	17
magnesia	16
manganese	19·125
mercury	35
nickel	16·625
potash	12·75
silver	21·5
soda	10·75
strontian	13·25
zinc	18·75
Nitrous acid	5·75
Nitric acid	6·75

O

Octohydrate of zirconia	15
Oil gas	2·625
Olefiant gas	1·75

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	ATOMIC WEIGHTS. Oxy. = 1
Potash protosulphate of iron	26·125
copper	27·75
magnesia	26·375
manganese	26·125
nickel	27
zinc	29·125
tartrate of soda .	35·5
Potassium . .	5
Protiodide of mercury .	40·5
Protochloride of phosphorus	6
tin .	11·75
Protohydrate of sulphuric acid	6·125
Protosulphuret of antimony	7·5
arsenic	6·75
iron .	5·5
mercury	27
platinum	14
potassium	7
tin .	9·25
Protoxide of antimony .	6·5
barium .	9·75
cerium .	7·25
chromium .	4·5
cobalt .	4·25
gold .	26
iron .	4·5
lead .	14
manganese .	4·5
mercury .	26
nickel .	4·25
platinum .	13
potassium .	6
rhodium .	6·5
sodium .	4
tin . .	8·25
uranium .	27

Q

Quadrochloride of azote .	19·75
Quadrosulphuret of potassium	13
Quadroxalate of potash .	31·875
Quadroxide of chlorine .	8·5
Quintosulphuret of potassium	15
Quintotitaniate of potash	36

R

Realgar . .	6·75
Red oxide of lead .	14·5
Rhodium . .	5·5

S

Saclactate of ammonia .	16·25
soda .	22·625
Saclactic acid . .	13
Seleniate of soda .	11
barytes .	10·75
Selenic acid . .	7
Selenium . .	5
Seleniet of arsenic .	9·75
Selenietted hydrogen .	5·125
Sesquicarbonate of ammonia	7·375
mercury	30·125
potash	16·875
soda	10·375
Sesquichloride of iron	10·25
Sesquifluoborate of ammonia	7·4375
Sesquisilicate of copper .	9·125
soda .	7
Sesquisulphuret of arsenic	7·75
iron .	6·5
selenium	8
tin .	10·25
Sesquisulphate of uranium	40
Sesquiuraniate of barytes	51·75
Silica	2
Silicate of alumina .	4·25
iron . .	6·5
zinc . .	7·25
Silicon . . .	1
Silver . . .	13·75
Soda . . .	4
Soda-oxalate of copper .	20·25
Soda-sulphate of alumina	58·875
lime .	17·5
Sodium . . .	3
Starch	17·75
Strontian . .	6·5
Strontium . .	5·5
Strychnia . .	47·5?
Sub-bichloride of sulphur	8·5
Suboxide of copper .	9
manganese	4
Subphosphuretted hydrogen	1·25
Subsesquacetate of copper	17·125
Subsesquarseniate of lead	28·75

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	ATOMIC WEIGHTS. Oxy. = 1
Succinate of ammonia	10·625
lead	20·25
soda	17
Succinic acid	6·25
Sugar	10·125
Sulphate of alumina	15·125
ammonia	8·25
barytes	14·75
bismuth	15
cadmium	17·5
cerium	15·625
cobalt	17·125
copper	15·625
iron	17·375
lead	19
lime	10·75
lithia	8·375
magnesia	15·375
manganese	15·125
mercury	33·25
nickel	17·125
platinum	19
potash	11
silver	19·75
soda	20·25
strontian	11·5
yttria	10·25
zinc	18·125
Sulphochyazic acid	7·375?
Sulphur	2
Sulphuret of antimony	7·5
arsenic	6·75
barium	10·75
bismuth	11
cadmium	9
calcium	4·5
cerium	8·25?
chromium	5·5
cobalt	5·25
columbium	20
copper	6
iron	5·5
lead	15
lithium	3·25?
magnesium	3·5
manganese	5·5
mercury	27
nickel	5·25
palladium	9
platinum	14
potassium	7
Sulphuret of rhodium	7·5
silver	15·75
sodium	5
strontium	7·5
tin	9·25
titanium	6
uranium	23
zinc	6·25
Sulphuretted hydrogen	2·125
Sulphuric acid	5
ether	4·625
Sulphurous acid	4

T

Tannin	8·75?
Tartar emetic	44·25
Tartaric acid	8·25
crystals	9·375
Tartrate of alumina	11·625
ammonia	10·375
barytes	18
bismuth	23·875
cadmium	19·5
cobalt	14·75
copper	16·625
iron	15
lead	22·25
lime	16·25
magnesia	13
manganese	15
mercury	34·25
nickel	12·5
potash	16·5
silver	25
soda	14·5
strontian	18·125
zinc	13·5
Telluretted hydrogen	4·125
Tellurium	4
Terfluosilicate of ammonia	11·875
Tin	7·25
Titanic acid	6
Titanium	4
Tredecahydrate of silica	16·625
Trisacetate of copper	23·5
Triscarbonate of bismuth	35
Trishydrate of silica	7·125
Trisnitrate of alumina	20·25
Trisulphate of alumina	21·875

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	ATOMIC WEIGHTS. Oxy. = 1
Trisilicate of iron	10·5
Tritantimoniate of potash	28·5
Tritiodide of azote	37·25?
Trititaniate of soda	24·25
Tritosulphuret of gold	31
potassium	11
Tritoxide of chlorine	7·5
Tungstate of lead	32·75
soda	29·5
Tungsten	15·75
Tungstic acid	18·75
U	
Uranium	26
Urate of soda	14·125
Uric acid	9
crystals	11·25
W	
Water	1·125
Y	
Yttria	5·25
Yttrium	4·25
Z	
Zinc	4·25
Zirconia	6
Zirconium	5

These tables being intended chiefly for the practical chemist, I have studied convenience of reference; and on that account have placed the chlorides, oxides, and sulphurets among the salts. The genera of salts are arranged in the alphabetical order.

The first and third of these tables are similar to two which I inserted at the end of the sixth edition of my System of Chemistry; but which I have here corrected, and considerably enlarged. The table of the *neutral* salts is new, and will be of very great use to practical chemists, as all the constituents of each salt, together with the weight of an integrant particle of it, will be seen at a glance of the eye. An example or two will show how this table is to be used. Suppose I obtain in any experiment 150 grains of dry sulphate of barytes, and that I want to know how many grains of sulphuric acid they contain, I must look among the sulphates for sulphate of barytes.

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Its atomic weight is 14·75, containing 5 of sulphuric acid. I say, therefore,

14·75 : 5 : : 150 : 50·847 = sulphuric acid in 150 grains of sulphate of barytes.

For sulphate of barytes, which is a calculation of perpetual recurrence in the laboratory, a good method is, to have a part of the process ready finished, and lying at hand for use. This may be done in the following way:

The logarithm of 5 is . .	0·6989700
Subtract the log. of 14·75 . .	1·1687920
Remains . . .	—1·5301780

This constant logarithm is to be added to the logarithm of the quantity of sulphate of barytes of which you wish to know the sulphuric acid. In the present example the quantity is 150 grains.

Logarithm of 150 . . .	2·1760913
Add	—1·5301780
Sum	1·7062693

Now, this is the logarithm of 50·847, the quantity found above.

Second example.—Suppose I have a solution containing 240 grains of nitrate of silver, and that I want to know from the tables how much common salt will just precipitate the whole of the silver. We see from the second table that the atomic weight of nitrate of silver is 21·5, and that of common salt 7·5. We say, therefore,

21·5 : 7·5 : : 240 : 83·72 = the weight of common salt required.

Third example.—Suppose I have a solution of 90 grains of oxalic acid crystals, and that I wish to know how much bicarbonate of potash will be necessary just to saturate the acid.

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From the third table (or last table) I find that the atomic weight of oxalic acid crystals is 9; consequently, 90 is equivalent to ten atoms. From the table of carbonates I find that the atom of bicarbonate of potash is 12·625. Consequently, 126·25, or ten atoms, is the quantity that would be required, if the bicarbonate contained only one atom of water; but, as it usually contains $1\frac{1}{2}$ atom of water, 131·875 grains will be requisite.

Fourth example.—Suppose I wish to prepare oxalate of zinc by double decomposition, from oxalate of ammonia and sulphate of zinc, what are the relative quantities of these two salts in crystals that must be used? The atomic weight of oxalate of ammonia is 8·875, and of sulphate of zinc 18·125. Consequently, we have only to take any equimultiples of these numbers; for example,

88·75 grains oxalate of ammonia,
181·25 grains of sulphate of zinc.

Dissolve these two salts in different portions of water, and mix the solutions. The whole oxalic acid and oxide of zinc will precipitate in combination, and nothing will remain in the liquid but a neutral solution of sulphate of ammonia.

These are only a few of the numerous uses to which these tables may be applied. It is obvious enough that if these tables were laid down upon a sliding rule, after the manner of Dr. Wollaston's scale of chemical equivalents, all these problems would be solved at once by adjusting the slide, without any arithmetical operation whatever. But the great multiplicity of substances, amounting to several hundred, would of necessity render such a scale so confused, that more time would be lost in looking for the substances, than in performing the arithmetical calculations from the tables.

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THE END

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Page 66, line 2 from bottom, for "$\frac{p-f}{\quad}$" read "$\frac{p-f}{p}$."
78, line 5, for "1·500" read "2·500."
93, line 2, for "Here" read "Hence."
ib. line 11, for "0·125+0·5555" read "0·125×0·5555."
124, line 17, for "two" read "too."
180, line 2 from bottom, for "DIOPTOSE" read "DIOPTASE."
275, line 5 from bottom, for "pape" read "paper."
302, line 1, for "of potash" read "and potash."
304, line 7, for "silicon" read silica."
336, line 6 from bottom, dele the word "owing."
364, line 2, for "11 2" read "11×2."
419, lowest line, for "Prout" read "Proust."
420, line 2 from bottom, for "copper" read "chlorine."
433, line 13, for "13·75 6·75" read "13·75+6·75."
441, line 12 from bottom, for "nitric muriatic" read "nitro-muriatic."
468, line 13, for "sulphuret" read "sulphur."

VOL. II.

273, line 12 from bottom, for "effervesces" read "effloresces."
277, line 6 from bottom, for "9·5" read "8·5."
372, line 8, for "Corinthia" read "Carinthia,"
407, line 15, for "2·57" read "2·75."

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